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THESIS

ASSESSMENTS OF ATMOSPHERIC EFFECTS
ON VHF AND UHF COMMUNICATIONS

by

Gary W. Culbertson

March 1990

Thesis Advisor: K.L. Davidson

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Nonstandard gradients of pressure, temperature and humidity in the troposphere create refractive conditions that affect electromagnetic waves by either increasing or decreasing VHF and UHF communication ranges. The Naval Ocean Systems Center (NOSC) has developed the Integrated Refractive Effect Prediction System (IREPS) to assess refractive conditions for a point of interest and provide video display or printouts of how the refractive conditions will affect various EM transmissions. A research cruise was conducted from 1-8 November 1989 in the Eastern Pacific and included 31 rawinsonde launches. The data from the rawinsondes was entered into IREPS PC Version 1.0 to assess the refractive conditions. The IREPS-generated refractive assessments where then compared to the GTE Sylvania Report and the Pacific Missile Test Center's Interim Procedure for Forecasting Refractivity Conditions (IPFRC). The results indicated that the GTE Sylvania climatology was not an accurate tool for assessing refractive condition at sea mainly because the GTE data set consisted of shore-based rawinsonde data. The IPFRC, based solely on synoptic weather parameters, obtained a 60 % success rate in predicting the likelihood of the presence of refractive conditions.

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ASSESSMENTS OF ATMOSPHERIC EFFECTS ON VHF AND UHF COMMUNICATIONS

by

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ABSTRACT

Nonstandard gradients of pressure, temperature and humidity in the troposphere create refractive conditions that affect electromagnetic waves by either increasing or decreasing VHF and UHF communication ranges. The Naval Ocean Systems Center (NOSC) has developed the Integrated Refractive Effect Prediction System (IREPS) to assess refractive conditions for a point of interest and provide video display or printouts of how the refractive conditions will affect various EM transmissions. A research cruise was conducted from 1-8 November 1989 in the Eastern Pacific and included 31 rawinsonde launches. The data from the rawinsondes was entered into IREPS PC Version 1.0 to assess the refractive conditions. The IREPS-generated refractive assessments where then compared to the GTE Sylvania Report and the Pacific Missile Test Center's Interim Procedure for Forecasting Refractivity Conditions (IPFRC). The results indicated that the GTE Sylvania climatology was not an accurate tool for assessing refractive condition at sea mainly because the GTE data set consisted of shore-based rawinsonde data. The IPFRC, based solely on synoptic weather parameters, obtained a 60 % success rate in predicting the likelihood of the presence of refractive conditions.

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I must thank my parents who have instilled in me the importance of education and gave up so much themselves in order to provide me with a sound education. I would also like to thank my wife, Paula, for her never ending support, patience, understanding and love.

I. INTRODUCTION

A. GENERAL

Much of the United States Navy's tactical voice communications consist of VHF and UHF line of sight or SHF microwave transmissions between two or more ships and associated aircraft at sea. When communicating in one of these three spectrums, the range of reliable communications or effective radio horizon is normally determined by the height of the transmitting and receiving antennas, the power of the transmitter and the sensitivity of the receiver. Nominal communication range tables exist using combinations of the above parameters for different frequencies and provide, at best, assumed ranges for equipment operating under ideal conditions. The range tables also use the 4/3's earth concept to determine horizon distance for a geometric ray [Ref. 1: p.1-8].

It is often the case that these nominal communication ranges are not realized, and greatly extended or diminished ranges are experienced. This can be explained in part by the refractive effects that temperature, pressure and humidity have on an electromagnetic (EM) wave propagating through the troposphere. It is a very difficult if not impossible task to accurately predict how these factors will affect communication ranges without taking an actual vertical sounding of the troposphere by means of a radiosonde. At sea, radiosonde data processing equipment is limited to aircraft carriers and selected amphibious/command and control vessels. Thus personal computer software programs, refraction models and general rules of thumb have been developed to try to summarize the effects of refraction on EM waves without taking an actual sounding of the troposphere.

The Navy first became interested in the effects that refraction has on an EM wave, especially in radar performance standards, during World War II. An enormous amount of research was conducted and published in the years to follow, but this information was mainly directed at the electrical and communication engineering communities and not the end user of the equipment. The sophistication of radars, communication suites, weapon sensor and guidance systems and electronic counter measures (ECM) systems continued to increase, and with the advent of the computer revolution, they have evolved into the highly capable microchip- oriented systems of today. The capabilities and limitations of these state- of-the-art systems must be fully understood by the decision makers who utilize them. With that in mind, a number of naval commands began

developing products that would allow these decision makers to determine the effects that tropospheric refraction would have on their EM equipment.

Some of the most ambitious refraction models and software programs currently in operation are using worldwide historical data collected and summarized by GTE Sylvania which has proven at times to be a poor tool for refractivity prediction [Ref. 2]. Some programs rely on synoptic weather patterns which may not represent microscale weather patterns at the point of interest. Other models may depend on satellite or infrared imagery analysis in which little experience exists for interpreting refractive effects. This is not to say that refractive effects prediction is a hopeless venture. Naval commands such as the Naval Oceans Systems Center (NOSC), the Pacific Missile Test Center (PACMISTESTCEN) and the Naval Environmental Prediction Research Facility (NEPRF) are very active in developing new refraction products which eliminate many of the negative features found in existing products.

B. PURPOSE AND SCOPE OF THIS THESIS

The purpose of this thesis is to acquaint the navy communication professional with the concept of tropospheric refraction. The discussion will be supported by an analysis of refractive conditions observed during a seven day research cruise off the California coast. This area is known to have extremes in atmospheric refraction, however, it is not unlike other regions in the world. This analysis will show how different refractive conditions affect surface-to-surface, surface-to-air and air-to-air UHF and VHF line of sight communications by using actual atmospheric sounding data that were entered into the Integrated Refractive Effects Prediction System (IREPS) . A comparison of the IREPS refractive conditions summary will be compared to the GTE Sylvania Report's historical data to determine its usefulness for predicting refractive conditions for a point of interest at sea. An analysis of the Pacific Missile Test Center's interim procedure for determining refractive conditions from synoptic weather parameters will be conducted and compared against actual radiosonde soundings and the associated IREPS propagation condition summary for five unique refractive conditions experienced during the research cruise. The purpose of this analysis is to determine if PACMISTESTCEN's interim procedure, based solely on synoptic weather parameters, is effective in predicting refractive conditions when actual atmospheric soundings cannot be obtained.

II. TROPOSPHERIC REFRACTION

A. GENERAL

The troposphere is the lowest part of the earth's atmosphere and extends vertically upward from the earth's surface to approximately 10 Km. A well mixed or *standard atmosphere* is characterized by decreasing temperature, pressure and humidity as altitude increases. In a standard atmosphere, temperature decreases at 6.5 degrees Celsius per Km when starting at the standard sea level temperature of 15 degrees C., and sea level pressure is assumed to be 1013.2 millibars. To make the standard atmosphere a better model, water vapor pressure, or humidity, must be included in the definition. A standard *moist* atmosphere then includes the above pressure and temperature values in addition to the standard water vapor pressure of 10 millibars at sea level which then decreases at a rate of 1 millibar per 1000 ft up to a maximum altitude of 10,000 feet or 3048 meters. [Ref. 3 : pp 1-4]

A standard atmosphere is just that, a standard to be used for measuring other conditions. Due to local and synoptic meteorological conditions, the troposphere is often not standard at all, and conditions are created that enable electromagnetic (EM) waves to be bent or refracted as the waves pass through the troposphere. These conditions constitute both horizontal and vertical stratification of the troposphere with common features consisting of rapid vertical increases in temperature, rapid vertical decreases in humidity, or a combination of the two. These rapid changes in temperature and humidity usually occur in the first kilometer of the troposphere and cause most of the significant refractive effects experienced by ships at sea communicating in the VHF or UHF spectrums [Ref. 4]. Figure 1 illustrates the extreme vertical variations in temperature and humidity gradients occurring mainly in the first kilometer of the troposphere.

B. EM SPECTRUM

Although refraction can occur at all wave lengths, it is most pronounced at wave lengths ranging from 10 m to 1 cm or 0.3 to 30 GHz, which covers the VHF, UHF, and SHF radio bands as illustrated in Figure 2 [Ref. 5 : p. 28]. Most naval line of sight communication occurs in one of these three bands, thus it is of interest to understand how refraction affects these wave lengths. The following paragraphs will discuss the physics of refraction and three common ways of measuring refraction.

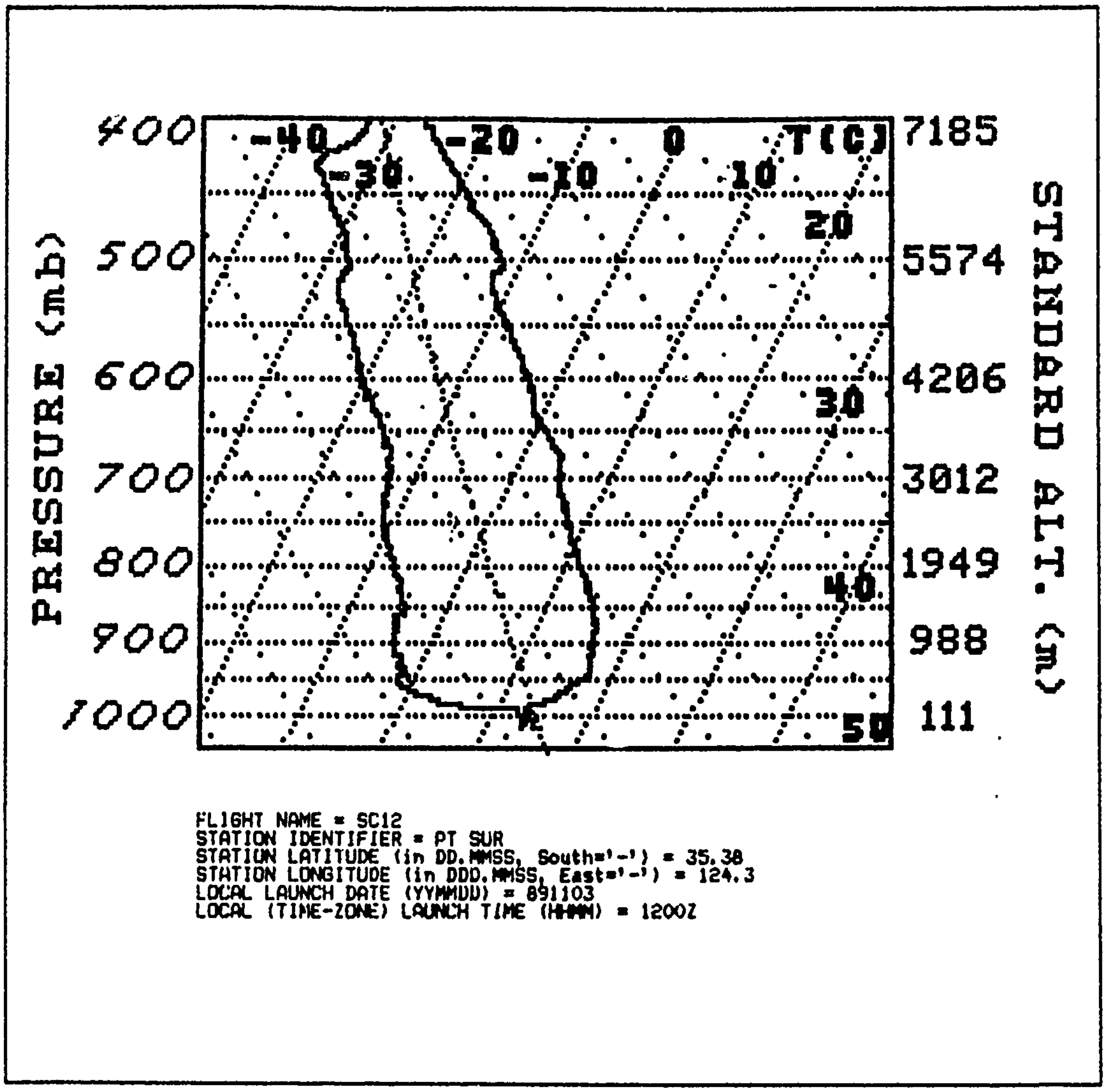


Figure 1. Skew-T Depicting Temperature, Pressure, and Humidity

C. REFRACTION

Refraction, as used in the context of this thesis, is the bending of an EM wave as it exits one medium and enters another. Refraction can best be explained by the application of Snell's law:

$$\frac{\sin\theta 1}{\sin\theta 2}=\frac{\eta 1}{\eta 2} \quad (1)$$

RADIO SPECTRUM	RADIO BAND DESIGNATION	WAVE LENGTH IN METERS	FREQUENCY IN HERTZ	REFRACTION IS IMPORTANT
		100,000	3×10^3	
	VERY LOW FREQUENCY VLF			
		10,000	3×10^4	
	LOW FREQUENCY LF			
		1,000	3×10^5	
	MEDIUM FREQUENCY MF			
RADIO		100	3×10^6	
	HIGH FREQUENCY HF			
		10	3×10^7	
	VERY HIGH FREQUENCY VHF			
		1.0	3×10^8	
	ULTRA HIGH FREQUENCY UHF			
		0.1	3×10^9	
MICROWAVE	SUPER HIGH FREQUENCY SHF			
		0.01	3×10^{10}	

Figure 2. EM Spectrum

Figure 3 illustrates Snell's law. An EM wave traverses medium n1 and strikes a more dense medium, n2. The wave bends towards the more dense medium to the point where Equation (1) is confirmed. Two good rules of thumb result from this discussion:

1. EM waves bend towards areas of higher n values.
2. More dense mediums usually have higher n values.

With the knowledge that the density of the atmosphere decreases with height, one can empirically deduce that EM waves have a tendency to bend back towards the earth; i.e., the higher n value.

A premise for Snell's law states that an EM wave front, when propagated in a complete vacuum, will follow a straight linear path in the direction in which it was propagated. Since the troposphere is certainly not a vacuum, an EM wave front will tend to refract back towards the earth. The index of refraction (n) is based upon the ratio of the velocity of a wave in a vacuum (represented by c) to the velocity of the same wave in a medium (represented by v) as given by Equation (2).

$$n = \frac{c}{v} \tag{2}$$

The most influential phenomenon affecting radio wave propagation is the medium's dielectric constant, ε. The dielectric constant takes on increasing values for mediums that contain more particles and is equal to 1 for a vacuum, approximately equal to 1.0003 near the earth's surface and approximately equal to 80 for water [Ref. 6 : p. 28]. Knowing that:

$$v = \frac{c}{\sqrt{\varepsilon}} \tag{3}$$

we can use the value of ε = 1 = c to state that:

$$n = \sqrt{\varepsilon} \tag{4}$$

The value of n at or near the earth's surface has been calculated to vary between 1.000250 and 1.000400. To enable scientists to work more easily with these numbers, the concept of refractivity was developed. Refractivity is represented by N and is defined by Equation (5).

$$N = (n-1) \times 10^6 \tag{5}$$

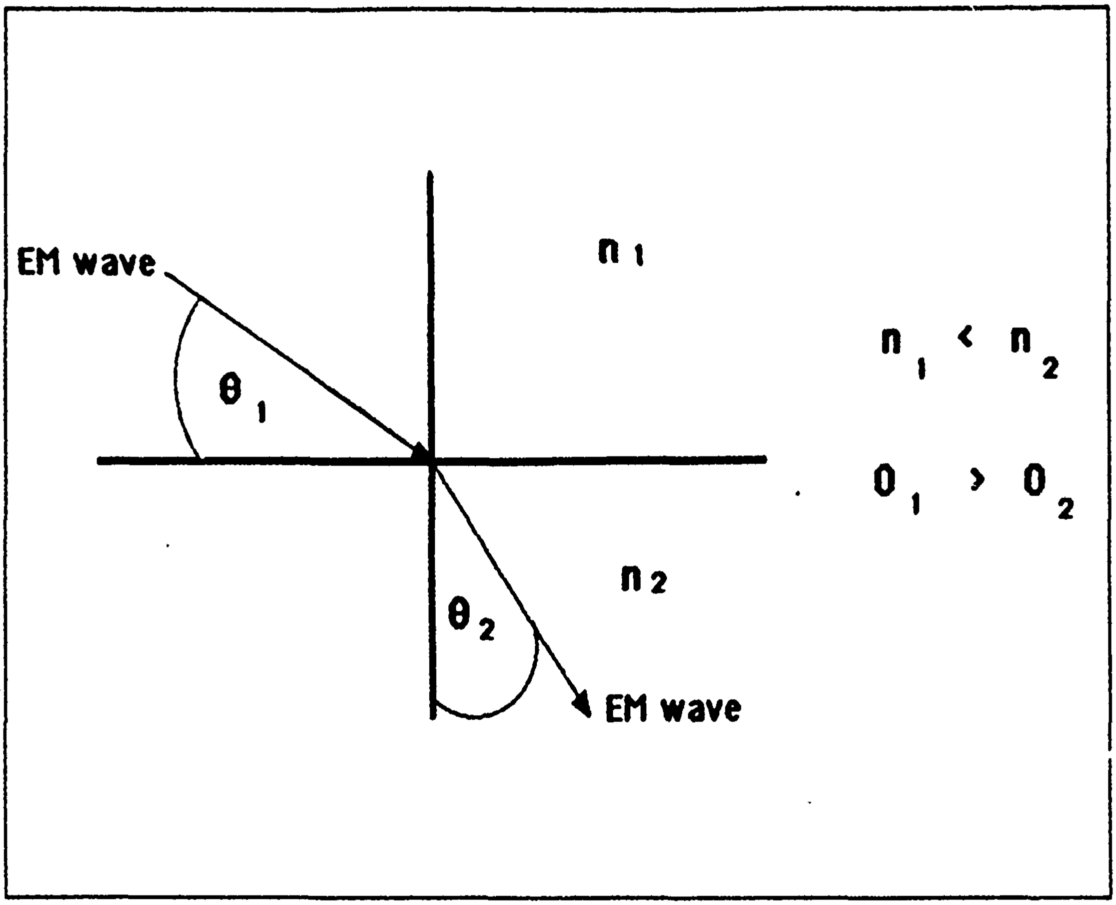


Figure 3. Graphical Depiction of Snell's Law for an EM wave.

From Equation (5), it is easily deduced that N units will vary between 250 and 400 [Ref. 6 : p. 90]. For a standard atmosphere, N would linearly decrease with height at a rate of dN/dh = -39 N units per 1000 meters, as illustrated by Figure 4 on page 9 .

Another common way to express refractive conditions is by modified refractivity (M), which is related to N by Equation (6) for h in meters and Equation (7) for h in feet.

$$M = N + 0.157 \tag{6}$$

$$M = N + 0.048 \tag{7}$$

For a standard atmosphere, dM/dh would linearly increase with height as illustrated by Figure 4. M units are used as an easy way to graphically determine trapping layers and ducts. A trapping layer is any region where $dM/dh < 0$. In this area, an EM wave will bend downwards relative to the earth. A duct is a region in which an EM wave is

trapped or localized to a waveguide-like channel. The transmitter must be located somewhere within the duct for trapping of the EM wave to occur. [Ref. 7]

D. DUCTS

Ducts can be one of three types: a surface based duct, an elevated duct or an evaporation duct. Each ducting type is illustrated in Figure 5. A surface based duct is characterized by an M value that is less at the top of the trapping layer than the M value at the surface, and thus the surface of the earth acts as the lower boundary of the duct. This type of duct usually ranges from 300 to 1000 meters in thickness, and because both the transmitting and receiving antennas are located within the duct, extended surface-to-surface communication ranges for frequencies above 100 MHz will exist. [Ref. 8 : p. 6]

An elevated duct is characterized by an M value that is greater at the top of the trapping layer than the M value at the earth's surface. These ducts can range in altitude from near the earth's surface to 6 Km. Elevated ducts can provide greatly extended communication ranges, especially for aircraft that are located within the duct. One major problem that elevated ducts can present is known as blind spots or communication holes [Ref. 8 : pp. 6-9]. This would occur when one unit is located above a duct and is trying to communicate with another unit located below the duct. In this case, the EM waves would follow Snell's law, but instead of bending towards the earth, they would bend upward and away from the earth.

Duct heights for surface based ducts can be determined by extending a vertical line downward from the top of the trapping layer (where dM/dh becomes positive again) to the surface. Duct heights for elevated ducts can be determined by extending a vertical line downward from the top of the trapping layer to the point where the line intersects the positive-sloped M gradient. These procedures are illustrated in Figure 5 .

The last type of duct is called an evaporation duct. These ducts only occur over areas of water and are caused by a rapid vertical decrease in humidity upward from the water's surface to an altitude determined by local meteorological conditions as illustrated in Figure 5. M will then rapidly decrease from the surface to a minimum value determined by the ambient humidity and then increase in its normal manner. Evaporation duct heights and strengths are very hard to accurately measure due to the dynamic nature of very small scale weather patterns that exist over open water. The evaporation duct usually only has pronounced effects on EM systems operating above 3 GHz by once again providing extended communication ranges. [Ref. 9]

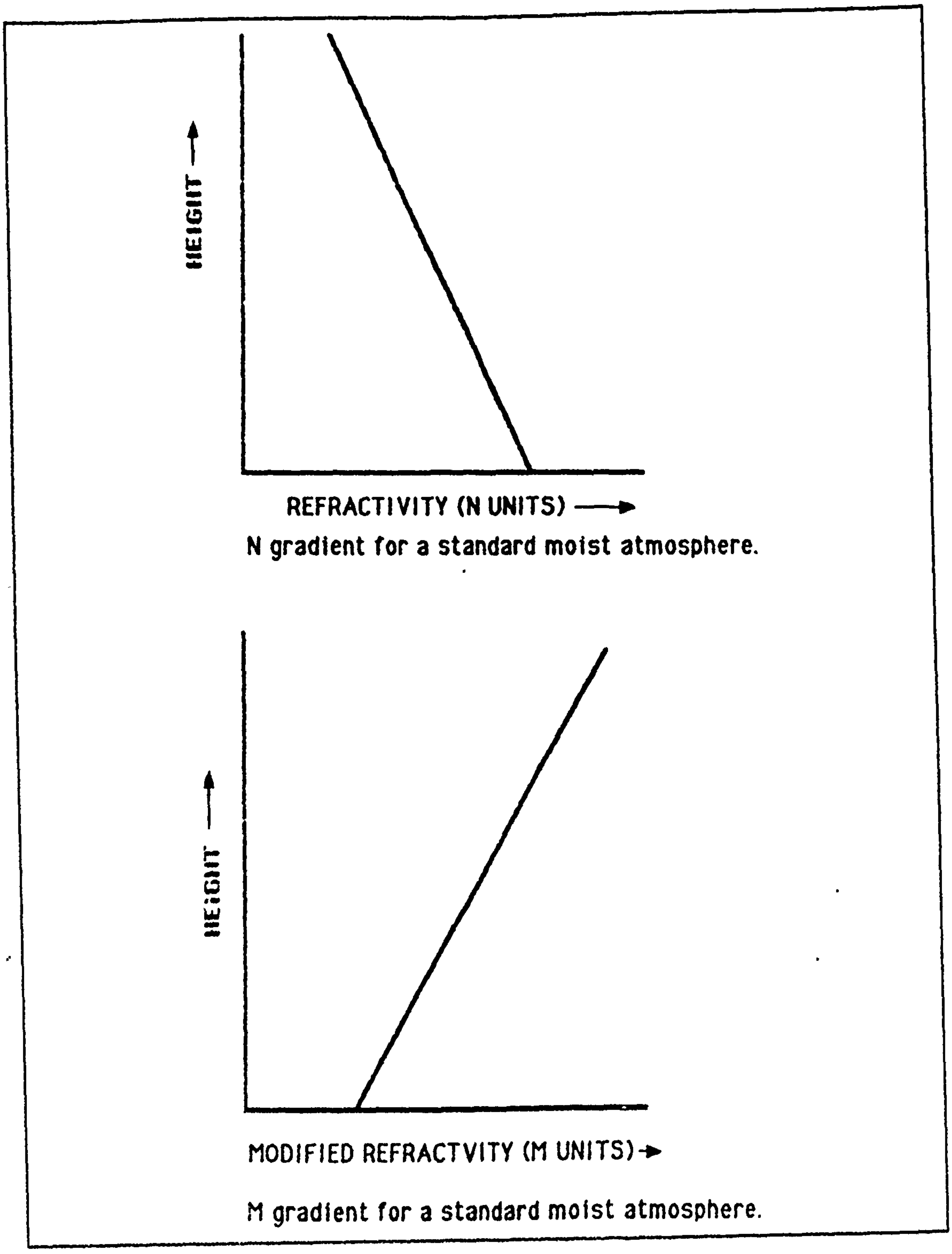


Figure 4. N and M Gradients for a Standard Moist Atmosphere

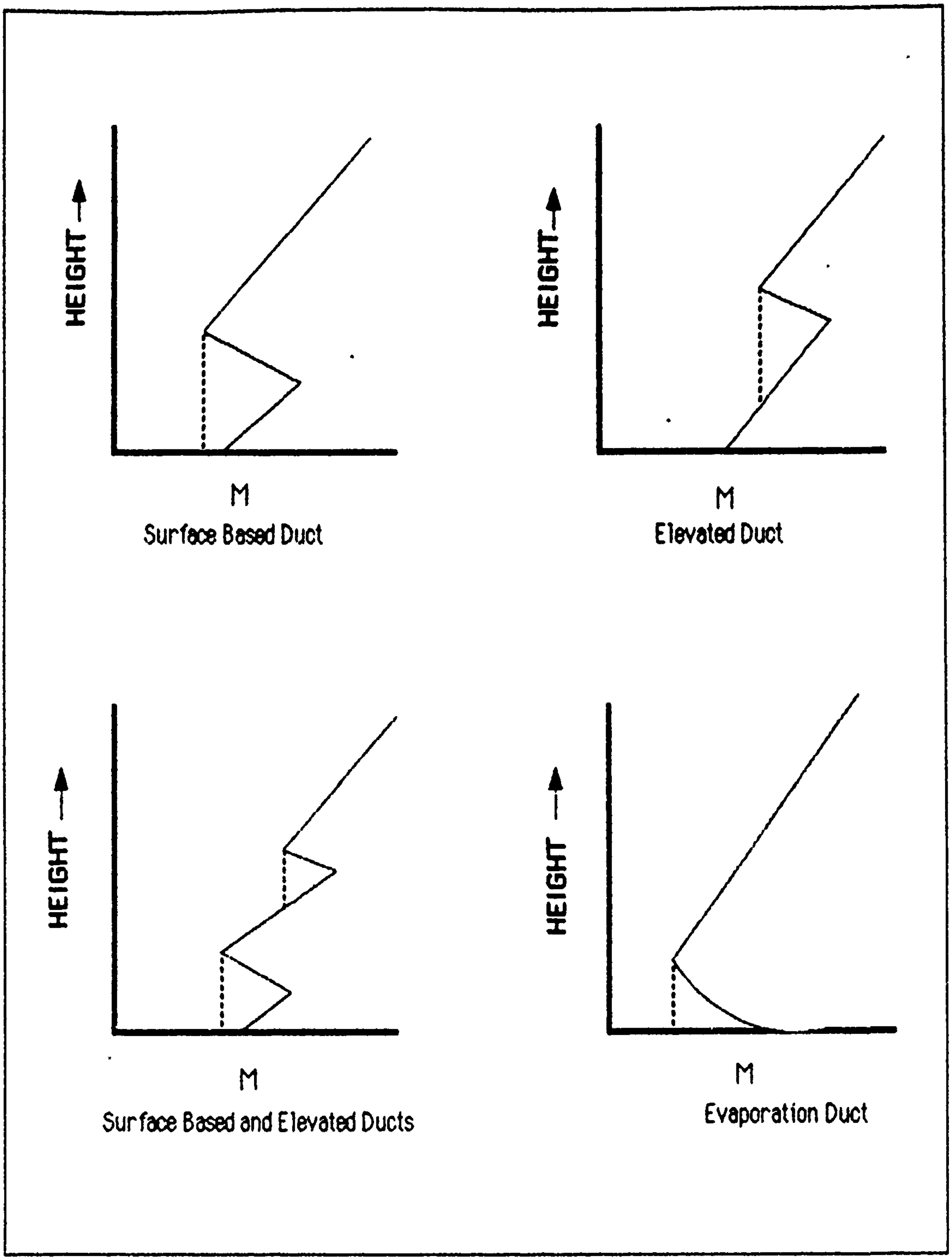


Figure 5. Determination of Duct Types by using M Gradients

The thickness of a duct is dependent upon the extent of the nonstandard vertical variation of humidity and temperature. It's this thickness that determines which frequencies or wave lengths are trapped within the duct. Figure 6 illustrates the effect of duct thickness in determining which frequencies are trapped or not trapped.

E. REFRACTIVITY ASSESSMENT PRODUCTS

1. IREPS

The United States Navy has been interested in the field of EM refraction since the days of World War II and has been sporadically investigating systems and algorithms that may predict trapping layers and their associated ducts. The most recent and exhaustive research into refractivity products began in 1973 at the Naval Electronics Laboratory Center (NELC) and was continued by personnel at (NOSC). Their efforts have culminated in the development of the Integrated Refractive Effects Prediction System (IREPS). IREPS revision 2.2 is a classified software package that has been programmed to run on the Hewlett-Packard 9845 computer and is operational on CV/CVN's and at the Fleet Numerical Ocean Center (FNOC). The IREPS software is also included as a subsystem in the Tactical Environmental Support System (TESS) which will be installed on CV/CVNs, LCCs, LHAs, LPHs, LPDs, and a number of shore installations. IREPS also is available in an unclassified but less capable PC version 1.0. The IREPS PC version 1.0 is capable of producing a propagation effects summary and was deemed sufficient for the analysis of refractive conditions during the research cruise. This analysis will be presented in detail in Chapter III. [Ref. 8 : p. 1]

To conduct an analysis of refractive conditions for a specific geographic point, IREPS 1.0 requires a vertical sounding of the troposphere. The sounding is accomplished by launching a radiosonde which measures temperature, pressure and humidity as it rises through the atmosphere. A radiosonde is comprised of a wet cell battery, transmitter, antenna, humidity sensor, thermometer, and a compact pressure gauge. These instruments are packaged in a small, styrofoam container and attached to a helium filled balloon. When the balloon and radiosonde are released or launched into the atmosphere, temperature, pressure and humidity data are transmitted back to the ground station. This raw data is transferred from the receiver to a PC for storage and later manipulation. Non standard temperature and humidity gradients are sought out from the raw data, and the values yielding these gradients are entered into the IREPS program.

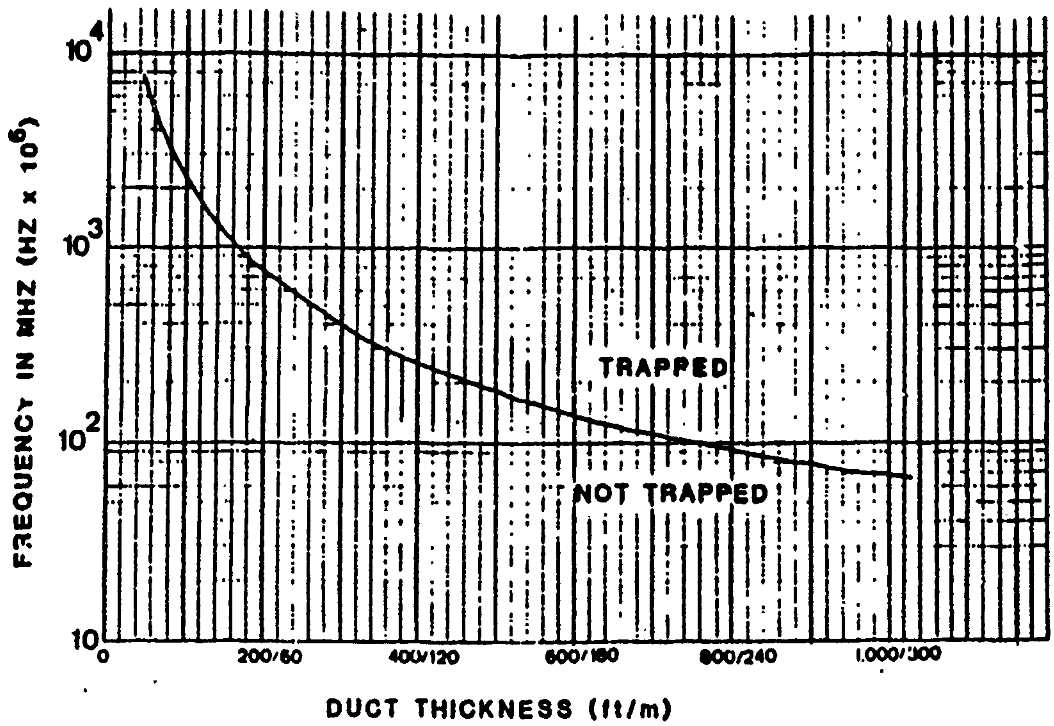


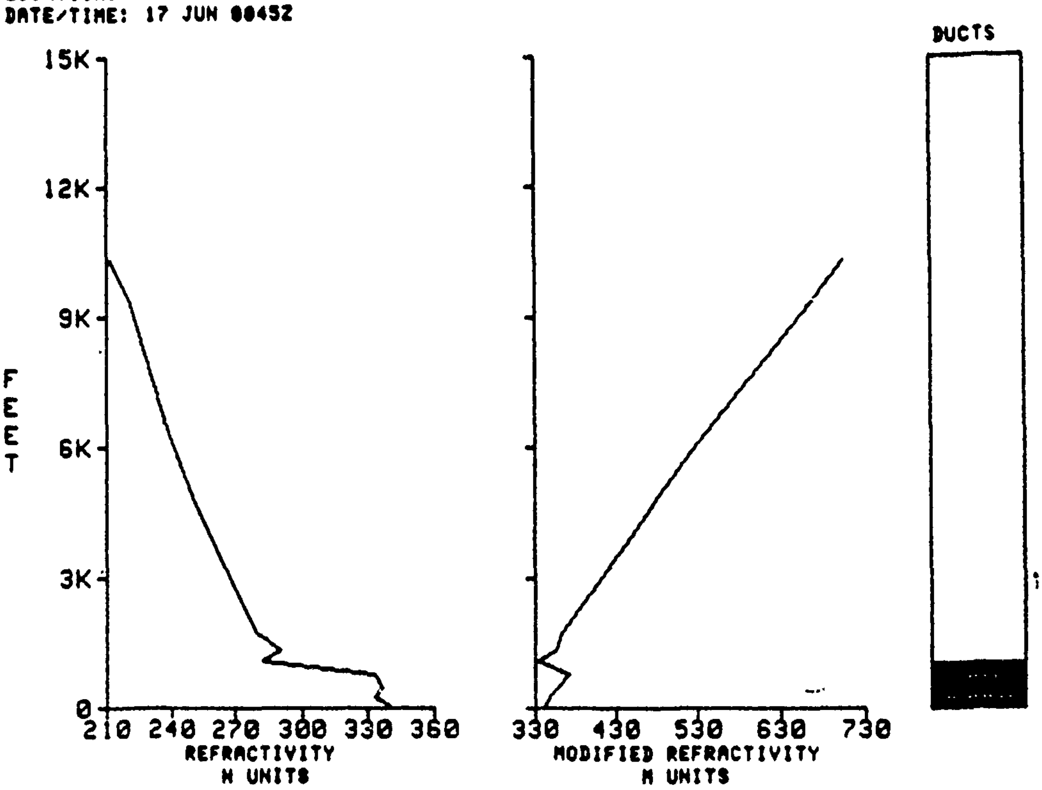
Figure 6. Frequencies Trapped with Respect to Duct Thickness

One of the most important products of IREPS for a communicator is the propagation condition summary. An example of a hard copy summary is illustrated in Figure 7. This product allows a person to choose a number of parameters which includes, but is not limited to, antenna height, antenna polarization, location, height units (m or ft), M or N unit display and the factors used to calculate the evaporation duct: namely sea water temperature, surface air temperature, surface relative humidity and station surface pressure. The output provides a textual explanation of refractive condi-

IREPS REV 2.2

**** PROPAGATION CONDITIONS SUMMARY ****

LOCATION: 31 56N 110 36W
DATE/TIME: 17 JUN 0045Z



WIND SPEED= 12.0 KNOTS

EVAPORATION DUCT HEIGHT= 8.5 METRES
= 28.0 FEET

SURFACE-TO-SURFACE
EXTENDED RANGES AT ALL FREQUENCIES

SURFACE-TO-AIR
EXTENDED RANGES FOR ALTITUDES UP TO 1,072 FEET
POSSIBLE HOLES FOR ALTITUDES ABOVE 1,072 FEET

AIR-TO-AIR
EXTENDED RANGES FOR ALTITUDES UP TO 1,072 FEET
POSSIBLE HOLES FOR ALTITUDES ABOVE 1,072 FEET
HOLES FROM SUPERREFRACTIVE LAYERS MAY EXIST ABOVE 1751 FEET

SURFACE REFRACTIVITY: 341 --SET SPS-48 TO 344

Figure 7. IREPS Propagation Conditions Summary

tions in addition to an M or N profile with an associated bar chart to depict ducts. [Ref. 10 : pp. 11- 12]

Another important product of IREPS is the coverage display. The coverage display provides a clear, graphical depiction of expected communication ranges for different altitudes taking into account the current or predicted refractive conditions. Figure 8 is an example of an IREPS generated coverage display for a common UHF transmission. [Ref. 10 : pp. 12-13]

IREPS classifies refraction into one of four types: trapping, superrefractive, standard and subrefractive. Table 2 shows the relationship of N and M gradients for each of the refraction types and includes expected range enhancement, if any. Figure 9 illustrates the ray geometry for each of the refractive conditions [Ref. 8 : p. 9].

Table 1. IREPS REFRACTION CLASSIFICATION

IREPS Classification	N Gradient dN/dh	M Gradient dM/dH	Range
Trapping	≤ -157 N/Km ≤ -48 N/kft	≤ 0 M/Km ≤ 0 M/kft	*Greatly Increased*
Superrefractive	-157 to -79 N/Km -48 to -24 N/kft	0 to 79 M/Km 0 to 24 M/kft	*Increased*
Standard	-79 to 0 N/Km -24 to 0 N/kft	79 to 157 M/Km 24 to 48 M/kft	*Normal*
Subrefractive	> 0 N/Km > 0 N/kft	> 157 M/Km > 48 M/kft	*Decreased*

2. GTE Sylvania Report

The GTE Sylvania radiosonde analysis report is the most exhaustive compilation of worldwide refractivity data ever collected. The intent of the report was to provide a refractivity product based on historical trends that could be used to predict refractive conditions when the launching of a radiosonde was impractical or impossible. The database consisted of nearly four million radiosonde soundings from 924 shore stations around the world covering the years from 1966 to 1969 and 1973 to 1974. A number of software programs were developed to perform a series of statistical analyses on the data. From these analyses, 20 distinct rectangular regions were created that ensured worldwide coverage. Table 2 provides a listing of these regions. In each of these regions, 17 of the most reliable stations for elevated data and 17 of the best stations for

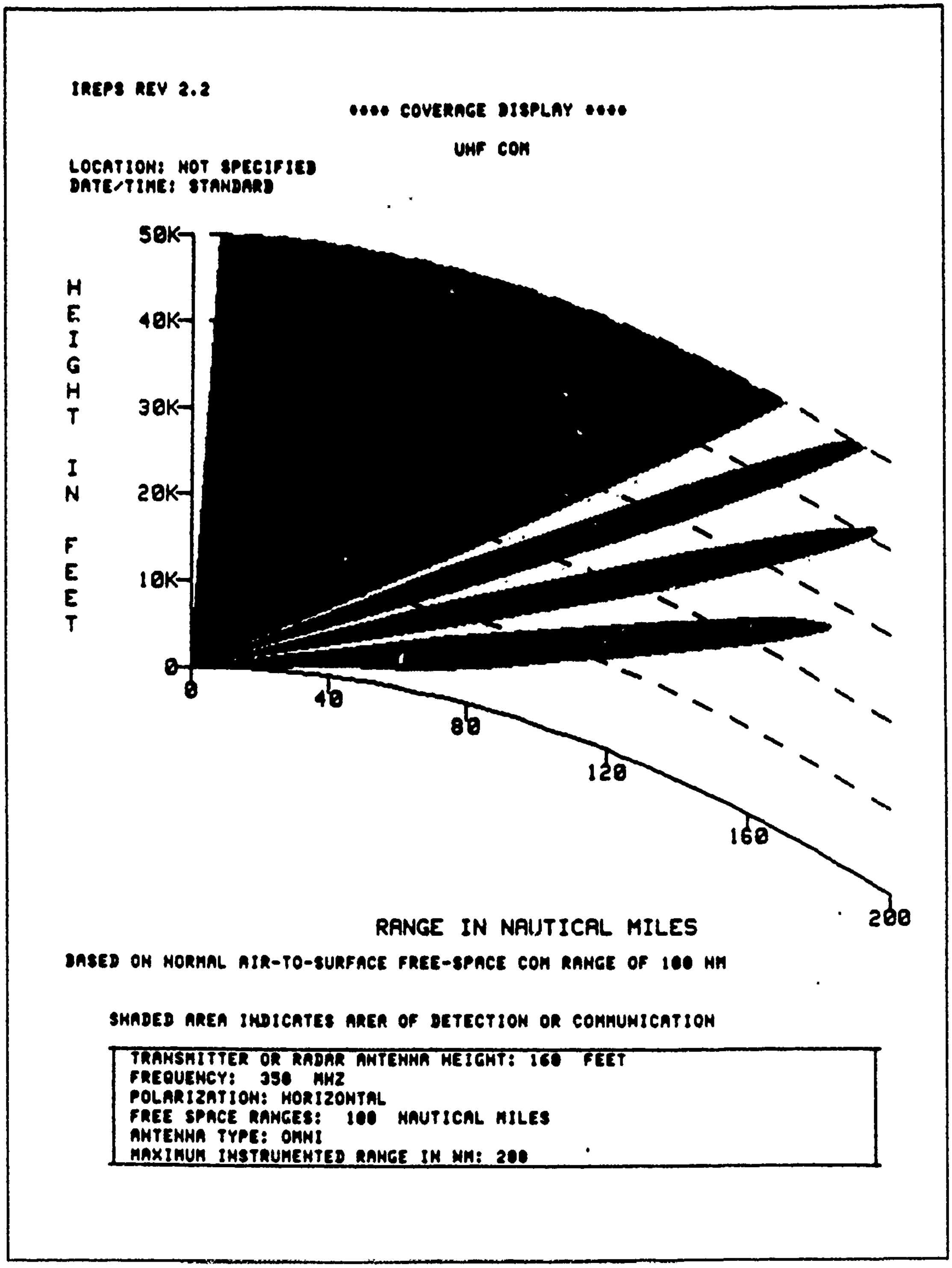


Figure 8. IREPS Coverage Display

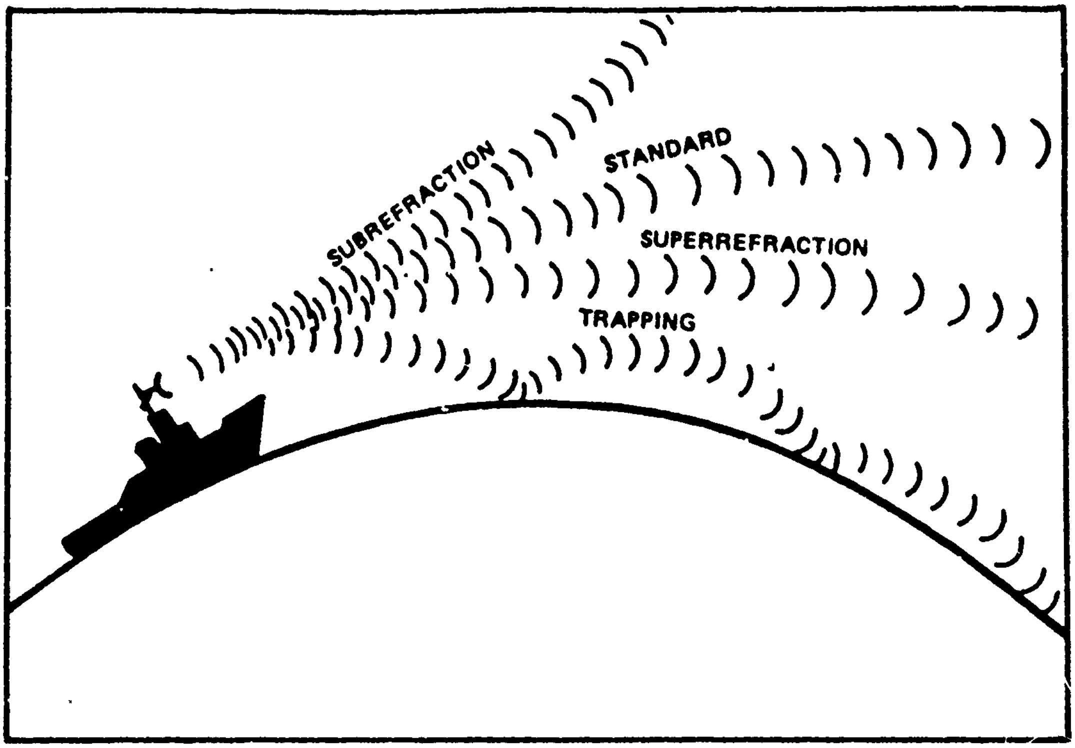


Figure 9. Ray Geometry

surface data were chosen for plotting propagation conditions. The type of plots generated for each key station of each region includes the following: [Ref. 11 : pp. 1-13]

1. Percent occurrence of elevated layers (monthly).
2. Optimum coupling heights of elevated ducts.
3. Minimum trapping frequency and surface-to-duct-bottom modified refractivity gradient for elevated ducts.
4. Coverage height for elevated ducts and superrefractive layers.
5. Optimum coupling heights for elevated layers.
6. Thickness for elevated layers.
7. Minimum trapping frequency for elevated ducts.

8. Intensity for elevated layers.

9. Percent occurrence of surface layers.

10. Surface refractivity and surface refractivity gradient over the first kilometer.

11. Thickness for surface layers.

12. Minimum trapping frequency for surface ducts.

13. Intensity for surface layers.

Table 2. GTE SYLVANIA REPORT REGIONAL BOUNDARIES

Number	Name	Latitude Limits (+ = N, - = S)		Longitude Limits (+ = E, - = W)	
1	Northern Europe	+46.0	+73.0	-10.0	+27.0
2	Mediterranean	+15.7	+50	-10.0	+37.0
3	West USSR	+28.0	+71.0	+25.0	+84.0
4	Africa	-38.0	+28.0	-26.0	+64.5
5	India	0.0	+34.0	+63.0	+110.0
6	East USSR	+32.0	+84.0	+82.0	+153.0
7	South China Sea	0.0	+33.0	+018.0	+135.0
8	Australia / Indian Ocean	-57.0	+8.0	+64.5	+154.0
9	Bering Sea	+28.0	+88.0	+152.0	-125.5
10	North Pacific	-11.0	+46.0	+153.0	-128.7
11	South Pacific	-70.0	+4.0	+149.5	-109.0
12	Canada	+42.3	+81.0	-128.0	-76.0
13	West USA	+25.0	+45.0	-125.5	-98.0
14	East USA	+28.0	+45.0	-99.0	-76.0
15	Central America	-10.0	+30.5	-129.5	-74.0
16	South America	-54.3	+6.0	+110.0	-26.0
17	North Atlantic	+20.5	+71.5	-78.0	-8.0
18	Central America	-11.5	+35.0	-78.0	-14.0
19	North Polar Region	+70.0	+90.0	-180.0	+180.0
20	South Polar Region	-90.0	-38.0	-180.0	+180.0

The data from the GTE Sylvania report comprises the majority of the historical data bank for IREPS which may cause a major inherent problem if a ship depends on a historical summary for propagation prediction. IREPS was designed for use by ships

at sea, whereas the data compiled into the GTE Sylvania report was acquired from shore-based stations. If an IREPS historical summary of refractive conditions is requested for a point of interest at sea, IREPS will use the closest radiosonde station to the point of interest. This station will most likely be a shore based station and may be hundreds of miles away from the actual point of interest. Therefore, the accuracy of the IREPS historical summary is often questionable. Figure 10 illustrates the components that comprise the IREPS historical EM propagation conditions summary.

IREPS REV 2.2 HISTORICAL EM PROPAGATION CONDITIONS SUMMARY

Specified location: 32 00 N 117 00 W (*) INDICATES INSUFFICIENT DATA
Radiosonde source : 72290 32 49 N 117 07 W
Radiosonde station height: 407 Feet
Surface obs source: MS120 35 00 N 115 00 W

PERCENT OCCURRENCE OF ENHANCED SURFACE-TO-SURFACE RADAR/ESM/COM RANGES:

FREQUENCY	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
100 MHz	3	3	3	2	3	3	3	2	2	5	3	4	3	4	3
1 GHz	37	21	29	37	24	30	31	13	22	40	21	31	39	25	32
3 GHz	43	26	35	43	30	37	30	17	27	47	26	36	46	32	39
6 GHz	56	37	47	55	42	48	52	28	40	58	34	46	60	44	52
10 GHz	77	65	71	73	65	69	76	62	69	80	64	72	80	69	75
20 GHz	87	83	85	84	81	83	87	82	85	89	82	86	89	85	87

SURFACE BASED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	25	22	23	18	26	22	24	15	20	33	21	27	23	27	25
AVG thickness Kft			.44			.20			.40			.70			.30
AVG trap freq GHz			.89			.86			1.4			.55			.78
AVG lyr grd -N/Kft			91			88			98			94			93

ELEVATED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	42	54	48	28	38	33	47	65	56	56	72	64	37	41	39
AVG top ht Kft			2.5			2.7			2.6			2.2			2.6
AVG thickness Kft			.60			.42			.64			.70			.56
AVG trap freq GHz			.20			.30			.18			.11			.21
AVG lyr grd -N/Kft			70			72			71			68			71
AVG lyr base Kft			2.2			2.5			2.2			1.7			2.3

EVAPORATION DUCT HISTOGRAM IN PERCENT OCCURRENCE:

PERCENT OCCURRENCE	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
0 to 10 Feet	9	9	9	10	10	10	9	8	8	9	10	10	8	8	8
10 to 20 Feet	8	13	10	9	15	12	7	12	10	7	12	10	7	12	10
20 to 30 Feet	13	22	17	13	21	17	14	23	19	13	23	18	11	20	15
30 to 40 Feet	15	22	18	11	18	15	17	25	21	18	24	21	14	20	17
40 to 50 Feet	11	12	12	9	11	10	12	13	13	13	12	12	10	13	12
50 to 60 Feet	7	6	7	6	6	6	8	7	8	7	5	6	8	7	8
60 to 70 Feet	4	3	4	4	3	4	4	3	3	4	3	3	5	3	4
70 to 80 Feet	3	1	2	3	2	2	3	1	2	3	1	2	3	2	2
80 to 90 Feet	2	1	1	2	1	2	2	1	1	2	1	1	3	1	2
90 to 100 Feet	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
above 100 Feet	27	10	18	30	12	21	23	7	15	24	9	17	30	12	21
Mean height Feet	74	45	60	79	48	63	69	41	55	69	43	56	81	50	65

GENERAL METEOROLOGY SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
# Accepted sndgs	414	405	410	403	395	399	417	405	411	409	419	414	428	400	414
% occur EL&SB dcts			4.4			3.2			4.7			6.3			3.4
% occur 2+ EL dcts			8.1			3.8			8.6			14			5.6
AVG station N			330			321			329			343			326
AVG station -N/Kft			19			16			20			24			18
AVG sfc wind Kts	10	11	10	10	11	10	11	12	12	10	10	10	9.3	10	10

Figure 10. IREPS Historical EM Propagation Conditions Summary

III. EASTERN PACIFIC RESEARCH CRUISE

A. DATA COLLECTION

The Naval Postgraduate School (NPS) conducts a semi-annual operational oceanography cruise on board the research vessel (R.V.) Point Sur to give students hands-on experience in collecting and analyzing oceanographic and meteorological data. The research cruise consisted of two separate legs. The first leg spanned from 1 - 4 November 1989 and covered the track illustrated in Figure 11. The R.V. Point Sur then returned to port at Moss Landing, California, for a student crew change. The second leg was conducted from 5 - 8 November 1989 and hugged the coast off Point Sur, California, as illustrated by the track in Figure 12 . This cruise provided the opportunity to collect refractivity data for the Monterey, California, bay area by means of radiosondes (rawinsonde).

Rawinsonde launches were conducted by the student watch teams and NPS meteorologists every six hours. Launch times of 0000Z, 0600Z, 1200Z, and 1800Z were chosen so that the collected rawinsonde data would coincide with NOAA synoptic weather charts and satellite imagery projections which were made available to students at the end of the cruise. The rawinsondes used on the research cruise were manufactured by the Viz corporation of Philadelphia, Pennsylvania. Bar coded calibration data is enclosed with each rawinsonde, and this information must be entered into and verified by the shipboard computer prior to launch. These rawinsondes utilize the Omega navigation system for tropospheric wind calculation which is accurate to 1 meter per second, a dry thermometer accurate to 0.2 degrees Celcius, and a dewpoint thermometer accurate to 1.0 degrees Celcius [Ref. 12 : pp. 5-6]. An adjustable frequency transmitter attached to the body of the rawinsonde provided raw data every ten seconds to a shipboard computer as the rawinsonde ascended through the troposphere. No data was recorded during the descent.

The raw data was then analyzed to determine if any obvious numerical errors were present. The errors found, if any, could include, but were not limited to, such factors as a weak or incomplete received signal from the rawinsonde, a faulty thermometer on the rawinsonde, weak or lost Omega signal or computer power fluctuations. Errors were then manually corrected, and a final corrected data set was produced. The corrected

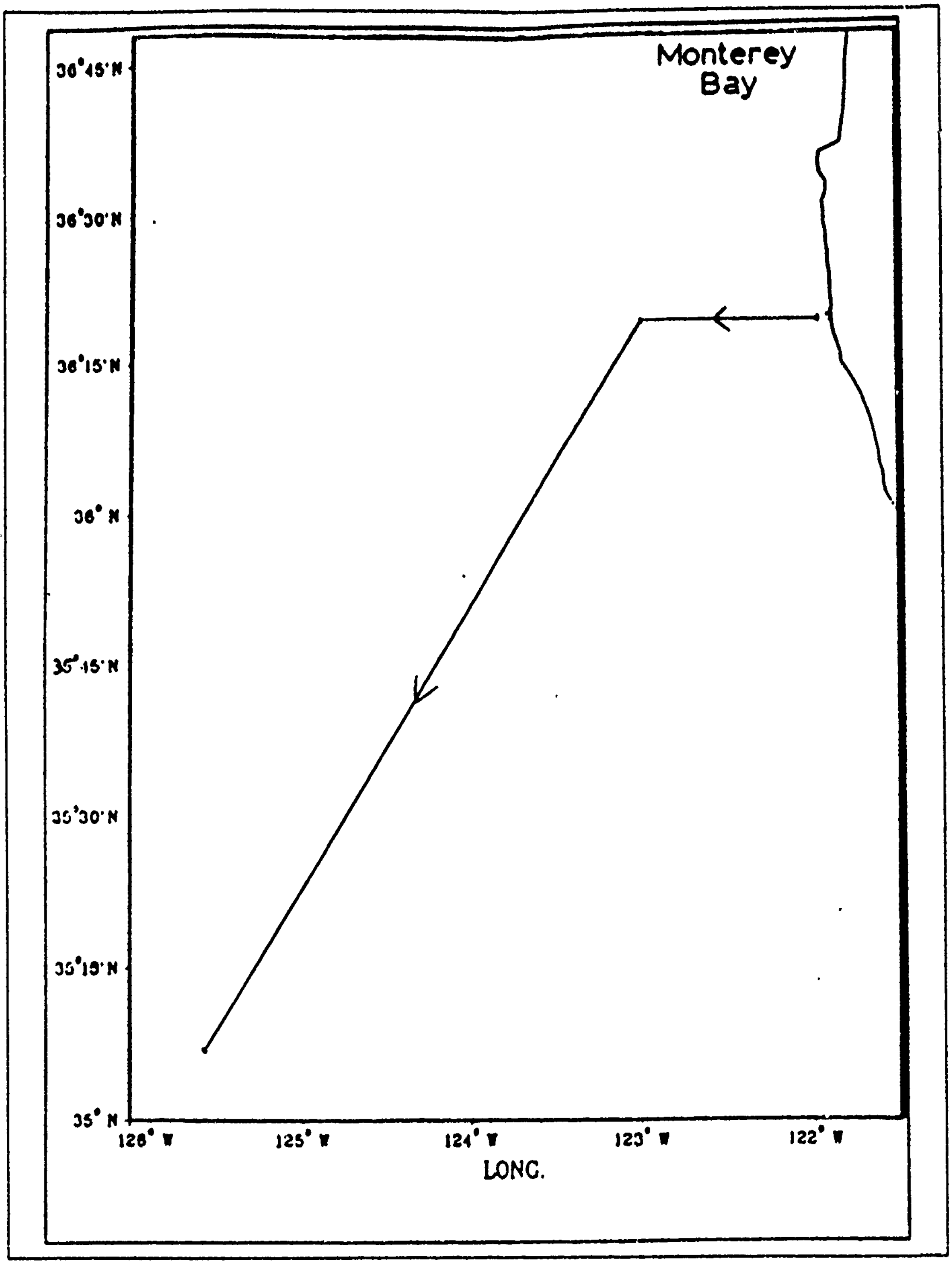


Figure 11. Research Cruise Leg 1

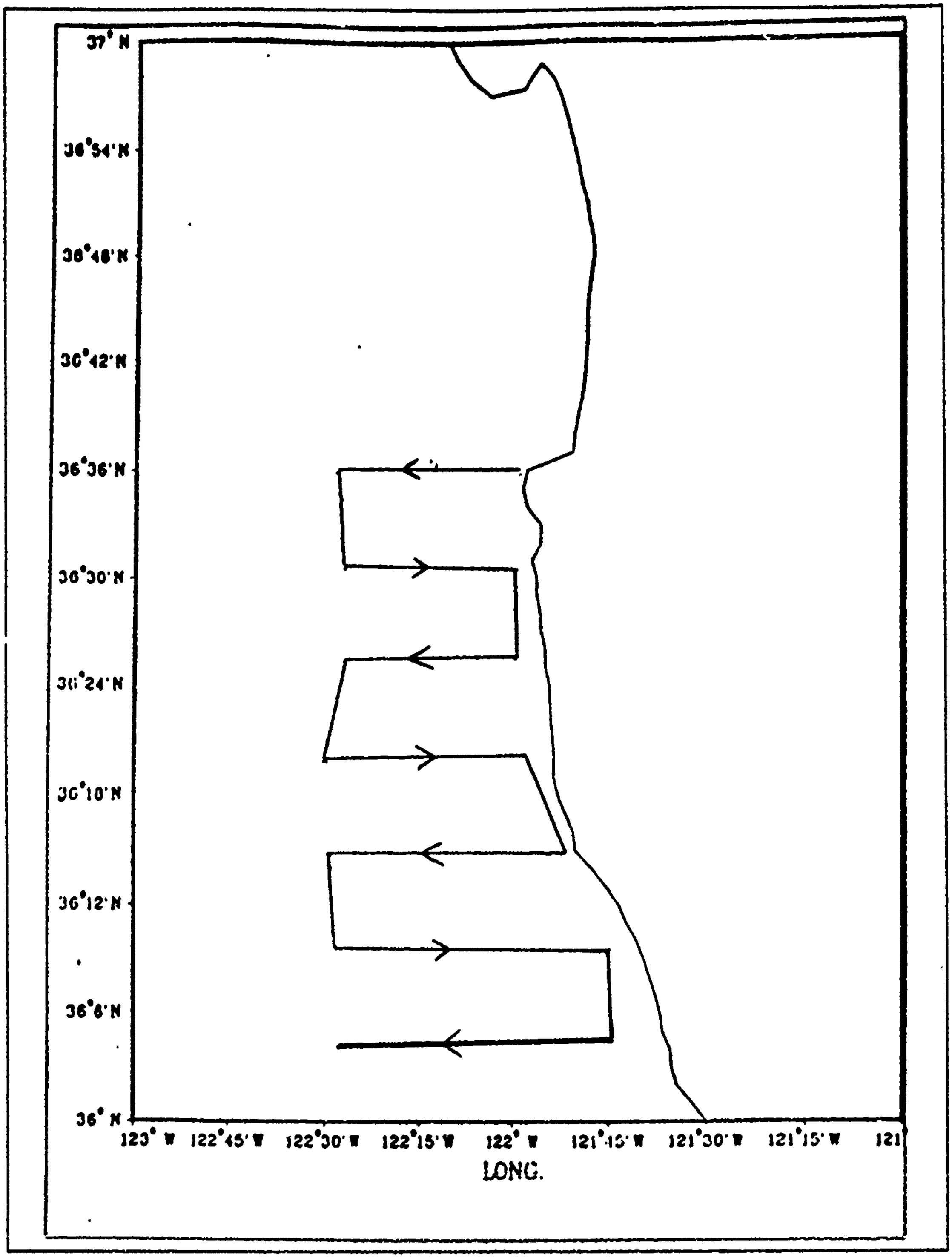


Figure 12. Research Cruise Leg 2

data set was used to generate skew-T diagrams and also provided the data that was manually entered into IREPS for ducting analysis.

B. DATA ANALYSIS

Thirty-one rawinsondes were successfully launched during the cruise and provided the data set for this analysis. The IREPS propagation condition summary and skew-T plots were used to obtain graphical depictions of the widely variable ducting conditions experienced as illustrated by Figure 13 through Figure 17. The variation in observed ducting conditions was attributed to changes in weather patterns. These changes ultimately affect the vertical temperature and humidity gradients, which in turn, determine the type and strength of a duct. Each ducting condition will be discused in the following paragraphs.

1. No Ducts

The total lack of ducting and the associated refractive layers occurred in only 3 out of 31 launches or 9.68 % of the time. Figure 13 illustrates the continuously increasing M unit with height and represents the standard, well-mixed atmosphere that contained no unusual deviations in temperature, pressure or humidity as the rawinsonde ascended the troposphere. Normal communication ranges could be expected in this type of environment.

2. Surface Based Ducts

Surface based ducts occurred with varying degrees of intensity in 6 out of 31 launches or 19.35 % of the time. They ranged in height from 107 m to 205 m with the average height being 175 m. Figure 14 illustrates the strength and height of a representative surface based duct which was encountered during the research cruise. Under this condition, communication ranges would be extended for all surface-to-surface UHF and VHF communications. Surface-to-air and air-to-air communications would be extended in range when propagated at a height less than the top of the duct. One interesting point to note is that all surface based ducts occurred on the first leg of the cruise and within 55 nautical miles of shore. This can be explained in part by coastal and synoptic meteorological features which will be discussed in detail in Chapter IV.

3. Single Elevated Ducts

Single elevated ducts were by far the most prevalent ducting phenomena recorded during the cruise and occurred in 19 out of 31 launches or 61.29 % of the time. The elevated ducts ranged in bottom height from 80 m to 614 m with the average being 223 m. The top of the ducts ranged in altitude from 261 m to 680 m with the average

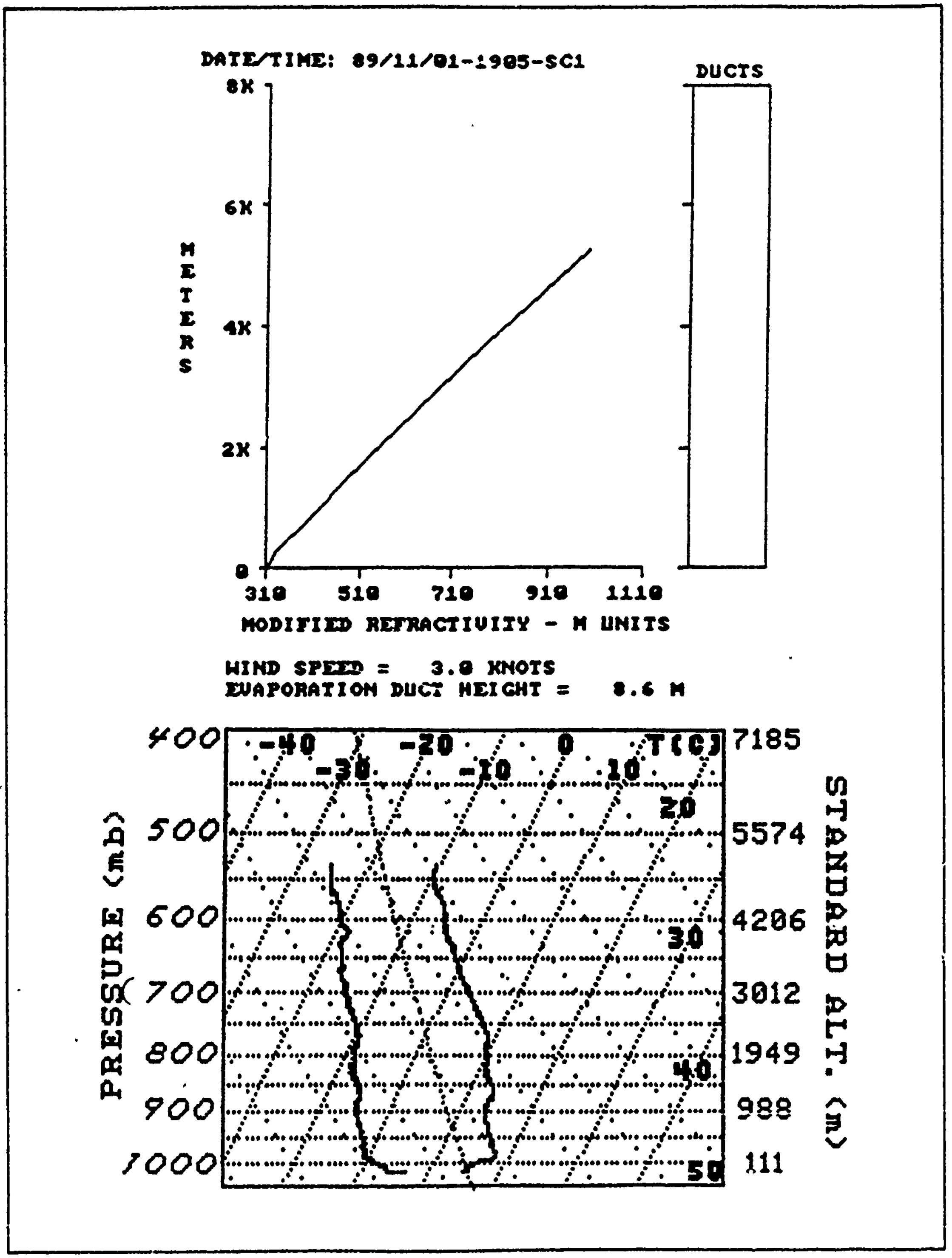


Figure 13. IREPS M Profile and Skew-T for a No Ducting Condition

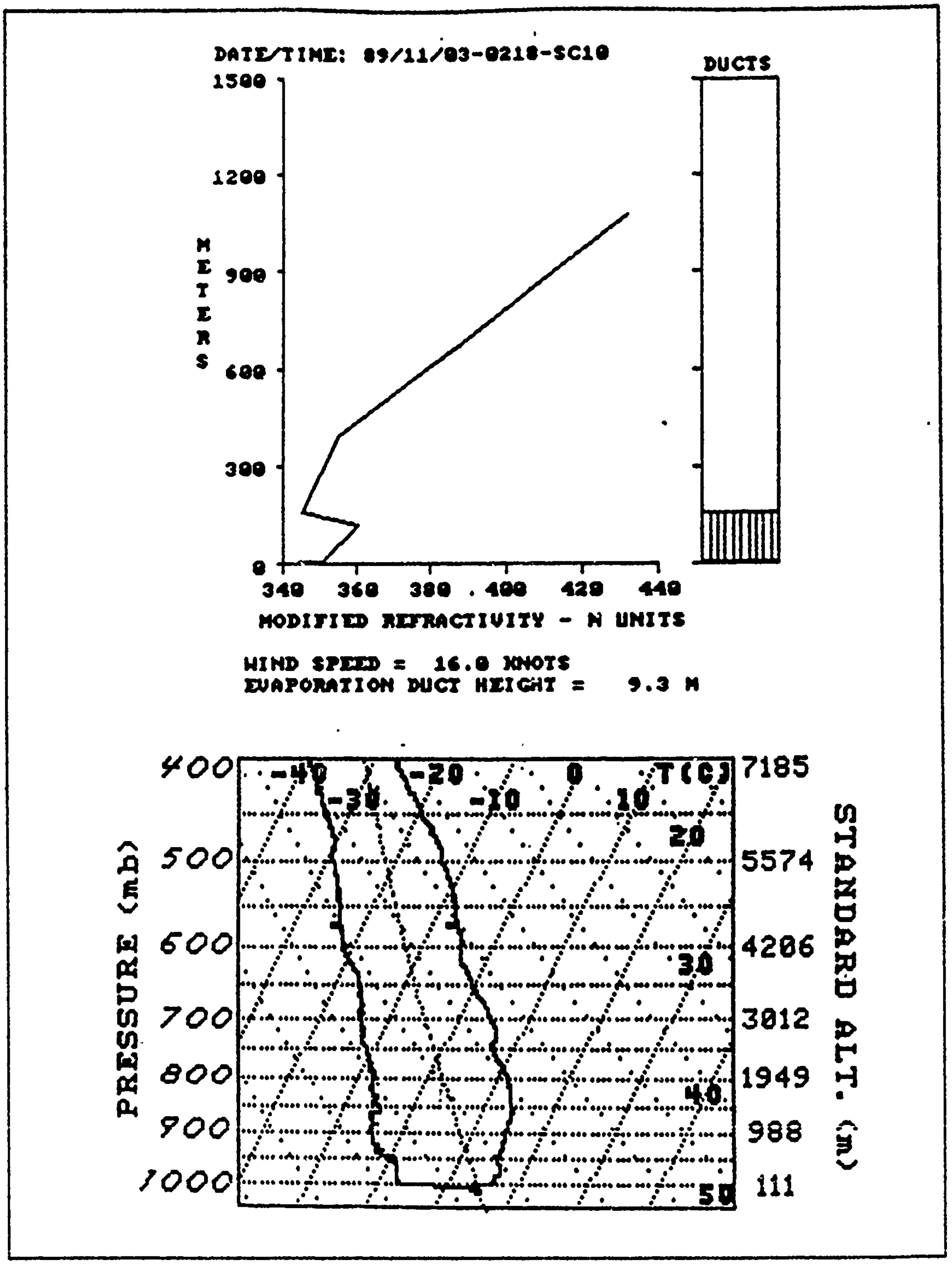


Figure 14. IREPS M Profile and Skew-T for a Surface Duct

being 451 m. The elevated ducts ranged in thickness from 66 m to 402 m with the average being 229 m. Figure 15 depicts a representative example of a single elevated duct case. Surface-to-surface UHF and VHF communication ranges would tend to be normal unless the duct were low enough to permit the transmitting and receiving antennas to be located within it. Surface-to-air communication ranges would tend to be normal. Air-to-air communication ranges would be extended if the aircraft was located somewhere within the duct.

4. Surface Based and Elevated Ducts

A surface based and elevated duct occurred simultaneously in only 1 out of 31 launches or 3.23 % of the time. Figure 16 shows the strengths and heights of both ducts. The surface based duct was very strong even though it only extended 46 m into the troposphere. The surface duct alone would provide extended surface-to-surface communication ranges in the UHF and VHF spectrums. Surface-to-air communications are also mainly affected by the surface based duct. Ranges would be extended in the area from the surface to 46 m, but holes are possible above 46 m due to interference nulls. Air-to-air communication would be extended in the areas comprising both the surface based and elevated ducts, with possible holes existing in the area between the ducts and the area above the elevated duct.

5. Two Elevated Ducts

Two elevated ducts occurred simultaneously in 2 out of 31 launches or 6.45 % of the time. Figure 17 illustrates the heights, strengths and separation of the ducts for both cases. Communication ranges for surface-to-surface and surface-to-air communications would be normal. Extended ranges would exist for air-to-air communications when the aircraft are within one of the two ducts, and holes or communication voids would be possible in the area between the two ducts and above the top duct.

6. Evaporation Ducts

Evaporation ducts existed in 100 % of the cases as would be expected when launching rawinsondes at sea. These duct thicknesses ranged from a minimum of 4.1 m to a maximum of 14.0 m with the average thickness being 9.8 m.

C. COMPARISON WITH GTE SYLVANIA CLIMATOLOGY

The IREPS PC version 1.0 used for research cruise refractivity analysis does not have the capability of producing the historical propagations summary product. In lieu of this product, a comparison of percent occurrence of elevated ducts and percent occurrence of surface ducts was performed using the actual research cruise soundings and

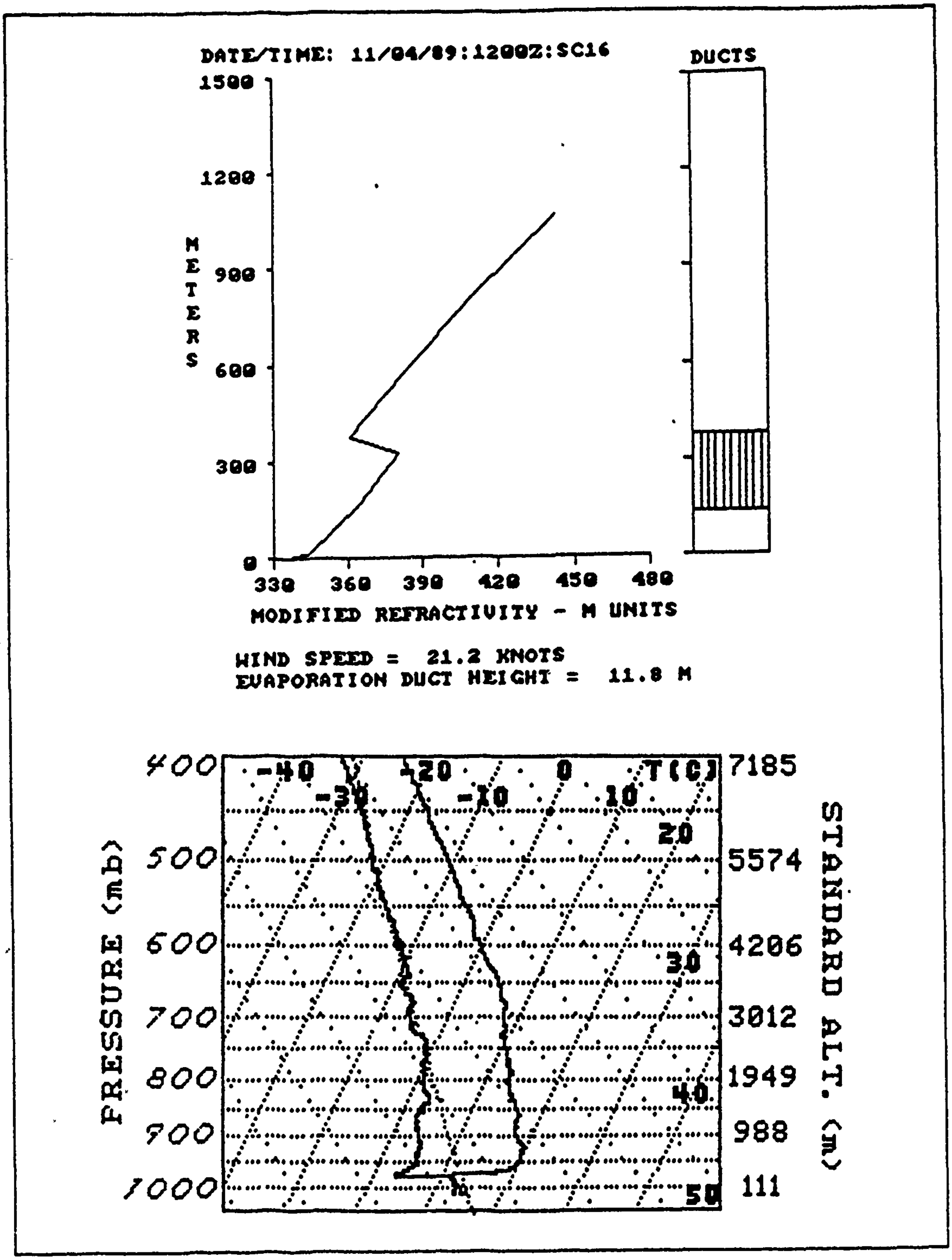


Figure 15. IREPS M Profile and Skew-T for Single Elevated Duct

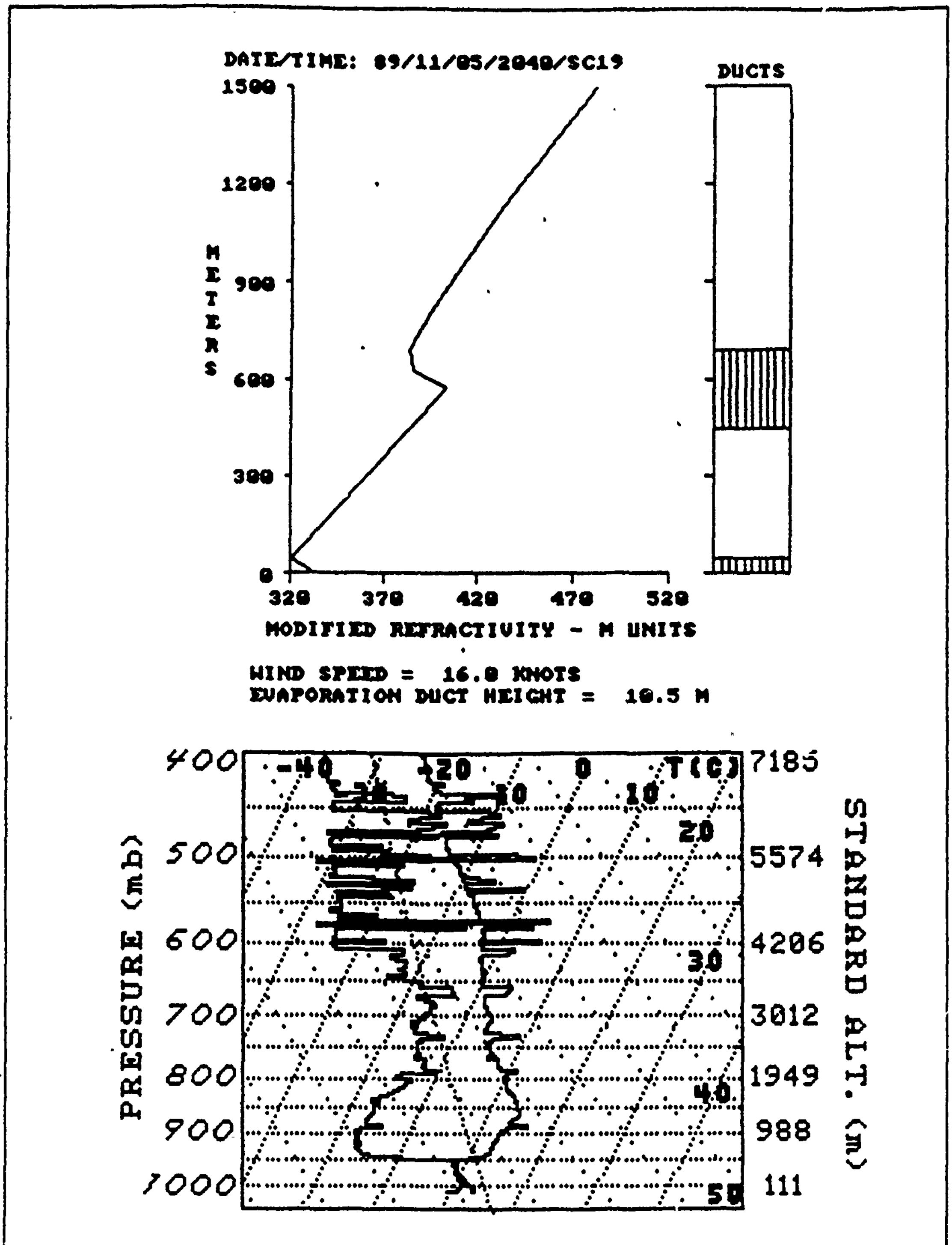


Figure 16. IREPS M Profile and Skew-T for Surface and Elevated Duct

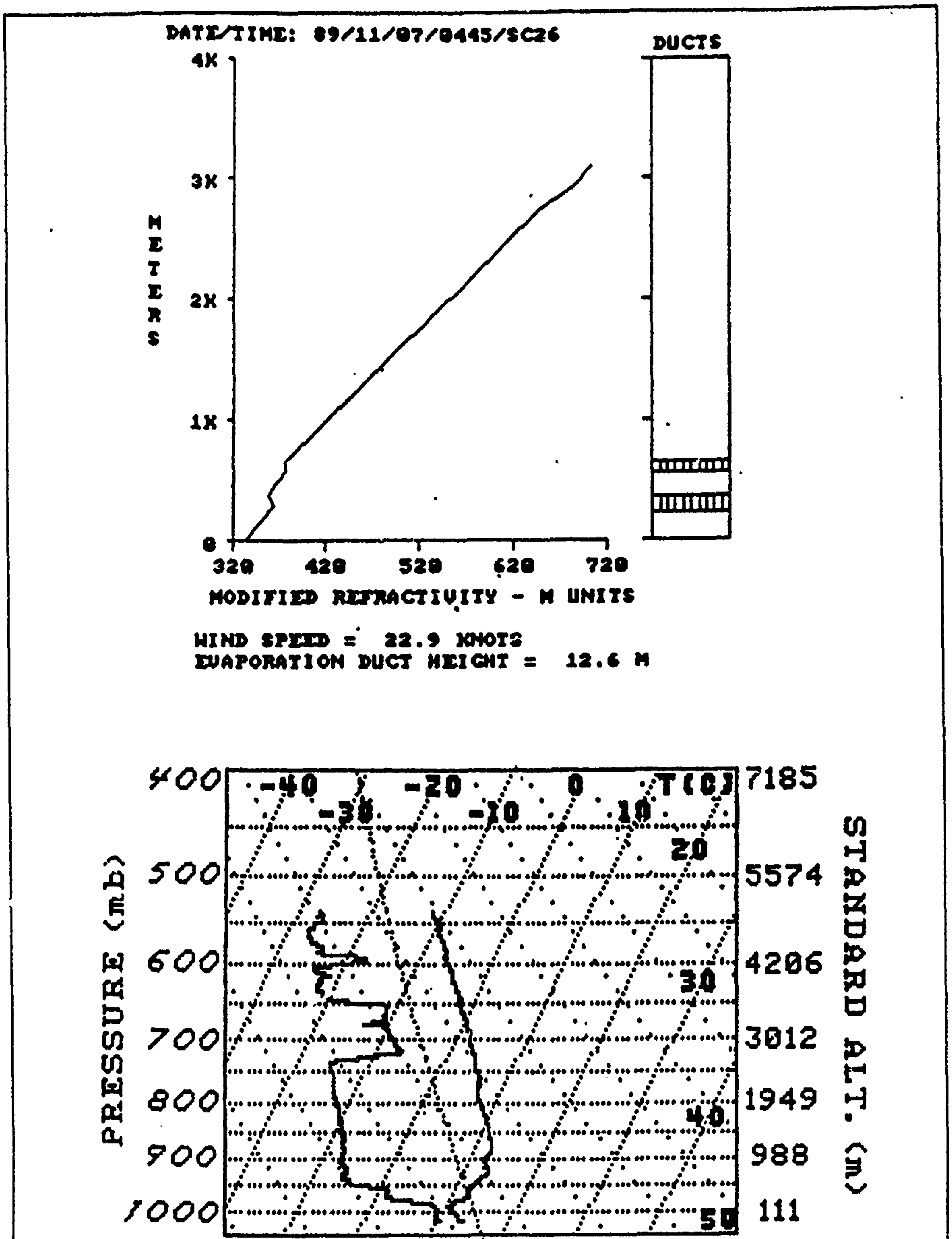


Figure 17. IREPS M Profile and Skew-T for Two Elevated Ducts

the GTE Sylvania report. San Francisco was the closest key radiosonde station to the research cruise operating areas, thus data from this station was used for the comparison.

1. Case one. Percent occurrence of elevated ducts

The percent occurrence of elevated ducts included all soundings in which one or more elevated ducts were present. This accounted for 22 out of 31 launches or 70.97 % of the time. Figure 18 is a graphical depiction of GTE Sylvania's findings, which indicate that the percent occurrence of elevated ducts for the month of November is approximately 37 %. There is a 33.97 % disparity between the actual soundings and the Sylvania report which suggests that actual soundings must be obtained for an accurate assessment of refractive conditions for a ship's point of interest.

2. Case two. Percent occurrence of surface ducts

The percent occurrence of surface based ducts included all soundings in which a surface based duct was present. This accounted for 7 out of 31 launches or 22.58 % of the time. Figure 19 illustrates GTE Sylvania's finding of approximately 5 % occurrence of surface based ducts for the month of November. The 17.58 % disparity between the Sylvania report and the research cruise soundings once again indicates that actual tropospheric soundings should be taken if an accurate assessment of refractive conditions is important.

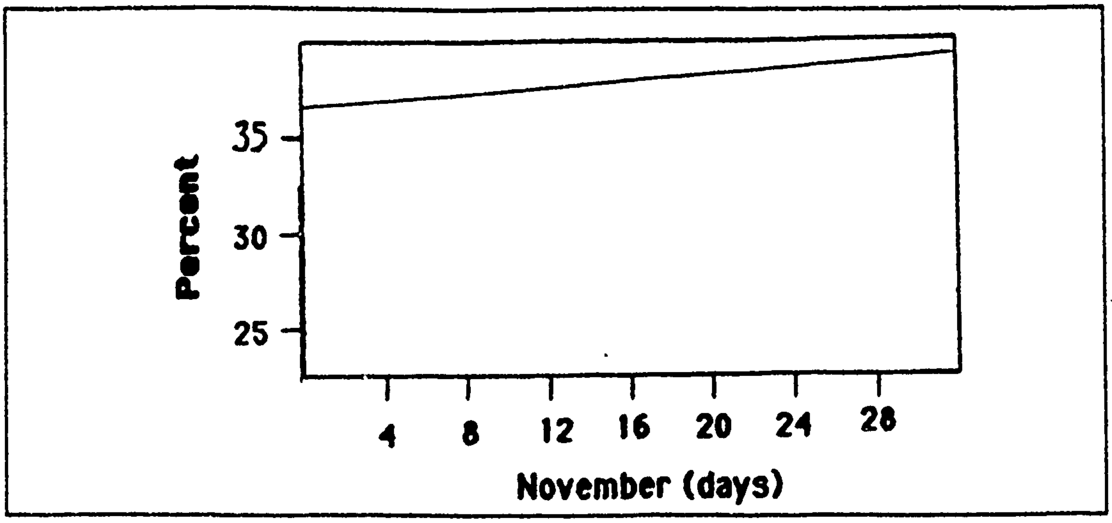


Figure 18. GTE Sylvania Report: % Occurrence of Elevated Ducts for Nov.

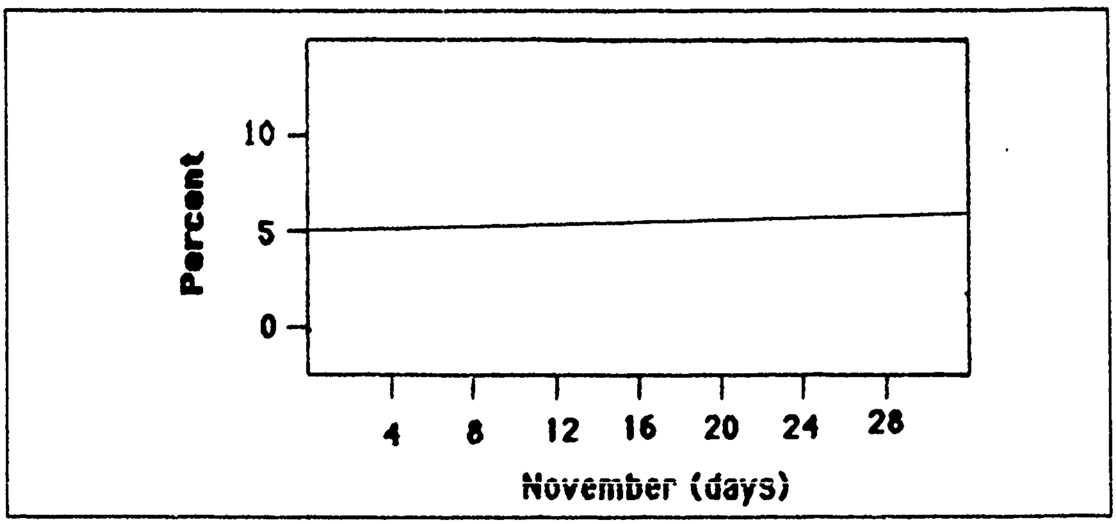


Figure 19. GTE Sylvania Report: % Occurrence of Surface Ducts for Nov.

IV. ASSESSMENT BASED ON SYNOPTIC REFRACTIVE PARAMETERS

A. GENERAL

Synoptic scale in meteorology refers to weather map scale phenomena. The relation between synoptic scale weather patterns on EM wave propagation and their association with the index of refraction, has been studied by the Navy for many years. Until 1976, the Navy had no written guidance for inferring refraction from large scale weather patterns. So at the request of the Commander, Third Fleet, personnel at NEPRF, NELC and PACMISTESTCEN developed procedures to predict tropospheric refraction conditions from generalized synoptic features. These procedures were incorporated into a COMTHIRDFLT TACMEMO in 1976 which was commonly referred to as the REG (Refractive Effects Guidebook) [Ref. 13 :pp1-1 - 4-1]. The REG was deemed an urgent requirement for the fleet, and thus its procedures were not extensively tested prior to operational use. This lack of testing led to a subsequent evaluation of the REG which proved that it was no better than using a random guessing procedure for determining refractive conditions [Ref. 14 : p. 18]. The REG was eventually canceled, and new research was begun to develop a more accurate prediction procedure for inferring refractive effects from synoptic weather parameters.

B. SYNOPTIC PARAMETERS

The most important concepts used in predicting refractive conditions from synoptic parameters are airmasses and pressure patterns. An airmass is defined as a large body of air that contains nearly uniform conditions of both temperature and humidity as it travels from its source. Airmasses are classified by the temperature and humidity characteristics at the place of origin, either polar or tropical, and their source, either maritime or continental. This classification permits the following four distinct airmass types: Polar maritime (Pm), Polar continental (Pc), Tropical maritime (Tm) and Tropical continental (Tc). Table 3 provides the source and properties of each type of airmass at its source. Airmass development is enhanced in areas where large high pressure systems dominate and are somewhat stationary. The quasi- stationary nature of the high pressure system allows the time needed for the underlying surface to influence the air above it. Airflow tends to diverge from these high pressure regions, and this divergence tends to give the forming airmass horizontal uniformity throughout the surface region. The

divergence within a high pressure system also leads to subsiding or sinking air which will tend to bring dryer and warmer air to the sea surface as the high pressure system moves from its source. As a result of the subsidence, an inversion level with conditions favorable to ducting may be formed. [Ref. 15 : pp. 5-7]

Table 3. AIR MASS TYPES

Air Mass	Source Region(s)	Properties at Source
Polar maritime (Pm)	Oceans in latitudes greater than 50 degrees. (approx.)	Cool, rather moist. Unstable.
Polar continental (Pc)	Continents in vicinity of the Arctic Circle; Antarctica.	Cold and dry. Stable.
Tropical maritime (Tm)	Sub-tropical oceans.	Warm, moist and rather unstable near the surface; dry and stable above.
Tropical continental (Tc)	Deserts in low latitudes; primarily the Sahara and Austriiian deserts but also S.W. USA and Mexico in the summer.	Hot and dry. Unstable.

A front separates two distinct airmasses. A cold front then would be the intrusion of cold *polar* air into a region, and a warm front would be the intrusion of warm *tropical* air into a region. Cyclones tend to develop along the perimeters of the fronts and their associated low pressure regions. The cyclones, which travel counterclockwise in the northern hemisphere and clockwise in the southern hemisphere, migrate and intrude into areas that have different pressure, temperature and humidity characteristics and may form inversion layers.

Figure 20 illustrates the subsiding air from the high pressure dominated airmasses and the rising motion of the air along the low pressure in the front which causes an inversion layer. It is these inversion layers, where pressure, temperature and humidity do not uniformly decrease with altitude, which cause refractive layers.

Airmasses, fronts and pressure systems can be easily identified on meteorological charts, and their movement can usually be accurately predicted for up to 24 hours. With that fact in mind, Helvey and Rosenthal of the Pacific Missile Test Center developed a number of thumb rules, a synoptic- refractive model, and an interim procedure for predicting refractive conditions by using synoptic meteorological data. These three products will be discussed in the following paragraphs. [Ref. 15 : p. 7]

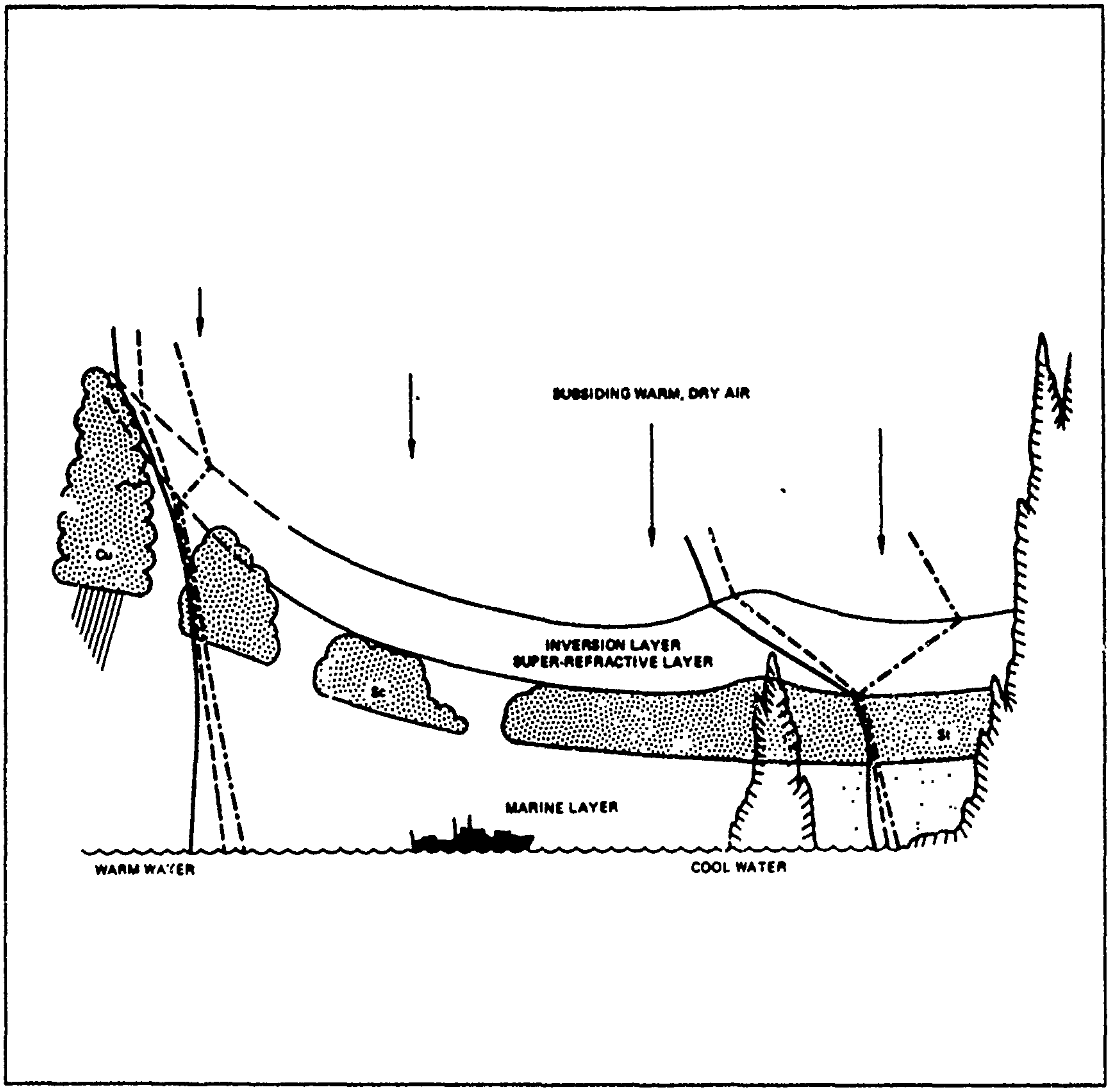


Figure 20. Inversion Conditions over Subtropical Oceans

1. Synoptic-refractive model

The Helvey and Rosenthal synoptic-refractive model was derived by performing a statistical analysis on observed synoptic parameters from ten selected North Pacific and North Atlantic subtropical locations. The statistical analysis plotted the frequency of duct occurrence against the following synoptic parameters: [Ref. 15 : pp. 10-17]

1. Isobar curvature (cyclonic and anticyclonic).
2. Distance from point of interest to center of high pressure region.
3. Surface pressure.

4. Surface wind direction.
5. Difference between 700 mbar and surface temperatures.
6. Surface pressure and surface wind direction collectively.

A separate model was developed for each of the two subtropical regions. Figure 21 illustrates the prediction model that can be used for the subtropical regions of the North Pacific ocean . The major problem with this model is that it is intended only for use in open areas which are far removed from the effects of continental air. This precludes the prediction of surface based ducts which may be caused by an offshore flow of continental air.

2. Thumb rules

Helvey and Rosenthal derived a series of thumb rules that can be utilized for predicting refractive conditions when no other data is available. They have based their thumb rules on a number of statistical studies and their personal experiences. These thumb rules are broken into the following four categories for use at any point of interest and include factors:

1. Favorable to elevated duct occurrence.
2. Favorable to surface based duct occurrence.
3. Affecting heights of elevated ducts.
4. Favorable to standard refractive conditions.

A complete listing of the thumb rules can be found in Appendix A. [Ref. 15 : pp. 26-30]

3. Interim Procedure for Forecasting Refractivity Conditions

This procedure utilizes 700 mbar charts, surface weather charts, satellite imagery and actual or predicted meteorological readings from the point of interest. This procedure could be used when vertical soundings of the troposphere are impractical or impossible. Points are awarded on the basis of how certain questions are answered. These points are then entered into an algorithm to give a weighted point total which indicates that ducting is either unlikely, possible, probable or very likely. Duct base altitude is derived from answering another series of questions which have no point values, but use similar meteorological information. This interim procedure (IPFRC) has been included as Appendix B. [Ref. 15 : pp. 30-34]

C. EVALUATION OF PACMISTESTCEN'S IPFRC

Five unique cases where chosen from the research cruise data set for an "after-the-fact" comparison with PACMISTESTCEN's IPFRC. The five cases depict represen-

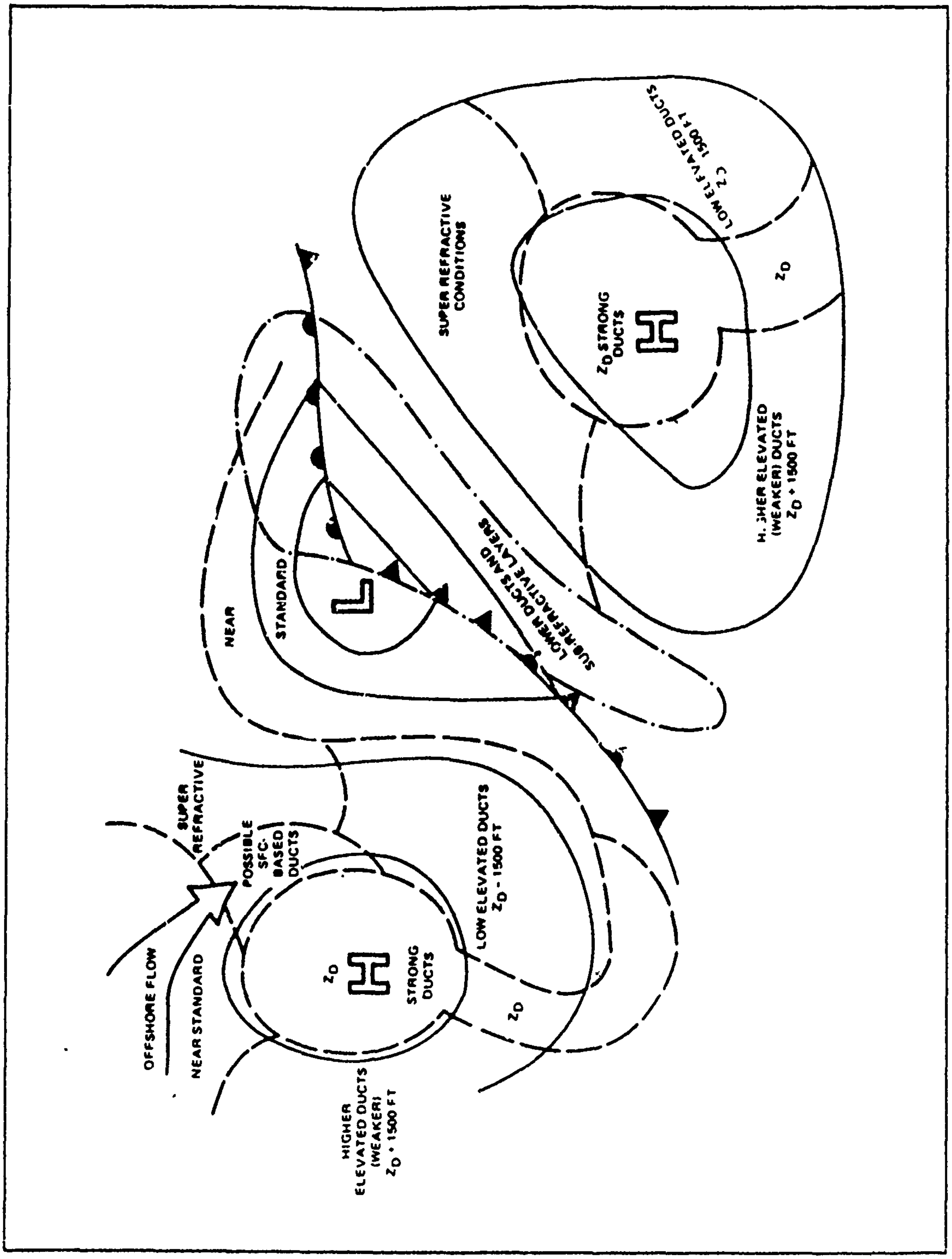


Figure 21. Model of Synoptic-Refractive Relationship

tative examples of the type of refractive conditions experienced during the research cruise. Figure 22 shows the location for each case. The IPFRC consists of two sections: the Interim Procedure for Duct Occurrence (IPDO) and the Interim Procedure for Estimating Duct Base Altitude (IPEDBA). For each case, surface weather charts, 700 mbar charts and satellite imagery were obtained upon return to port for the time period closest to the actual rawinsonde launch. Only the charts, satellite imagery and recorded meteorological factors of surface pressure, wind direction and presence or absence of offshore air flow were used as input to the IPFRC. Appendix C contains the IPFRC calculations for each case. The results of the IPFRC were then compared with the IREPS propagation conditions summary to determine the effectiveness of the IPFRC on a case by case basis. The following is a detailed description of each case.

1. **Case one**

- Location: 36-47.71 N, 121-58.10 W.
- Date/Time: 01 Nov 89, 1905 Z.

Figure 23 and Figure 24 show the surface and aloft synoptic patterns at the time the rawinsonde was launched. These features were interpreted for use in questions 5 - 15 of Appendix B. The local weather conditions where noted as clear with no cloud cover and included a light land to sea flow of air. The IREPS refractive conditions summary for this rawinsonde launch indicated a lack of ducting at any altitude. The M gradient and skew-T plot, as seen in Figure 25, show a very smooth and steady increase in modified refractivity and the associated decrease in both temperature and humidity as altitude increases. This is almost a perfect example of a standard, well- mixed atmosphere in which communication ranges would be normal; i.e., ranges would follow the 4/3's earth prediction.

The IPDO calculation for case one indicated that ducting was *very likely*. Question number 19 of the IPEDBA indicates that the base of the duct is zero, or in other words, a surface based duct. The single most important factor that made the IPDO determination completely opposite from the IREPS determination was question number 12, concerning land to sea flow of warm air. The determination to answer question 12 as yes, was because the land air temperature was two degrees Celsius warmer than the sea surface temperature, and the wind was from 068 true. Because the difference in temperatures was considered small, the IPDO was recalculated. The new point total indicated that ducting was *possible* , which is still an inaccurate prediction according to IREPS.

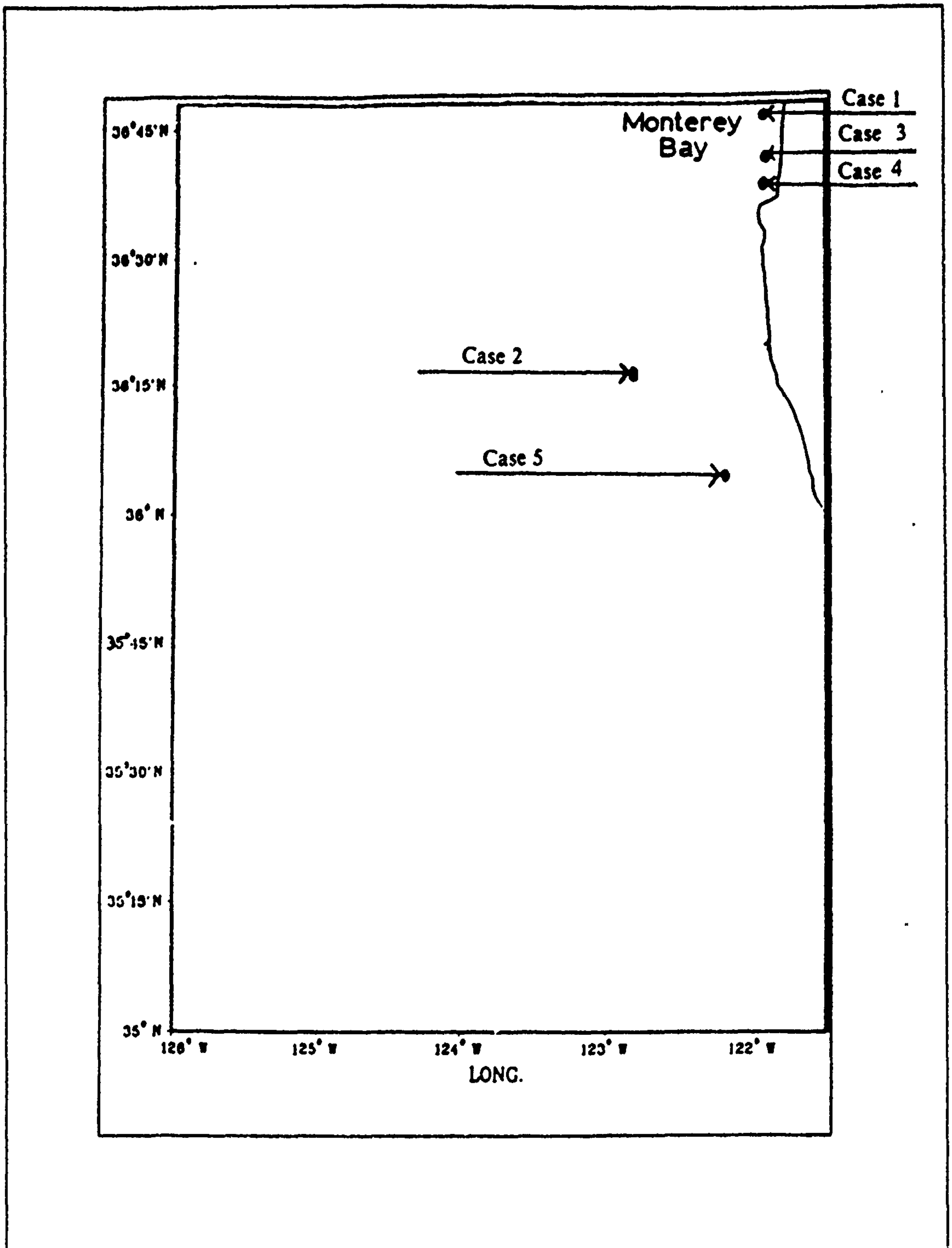


Figure 22. Rawinsonde Locations used for Testing the IPFRC

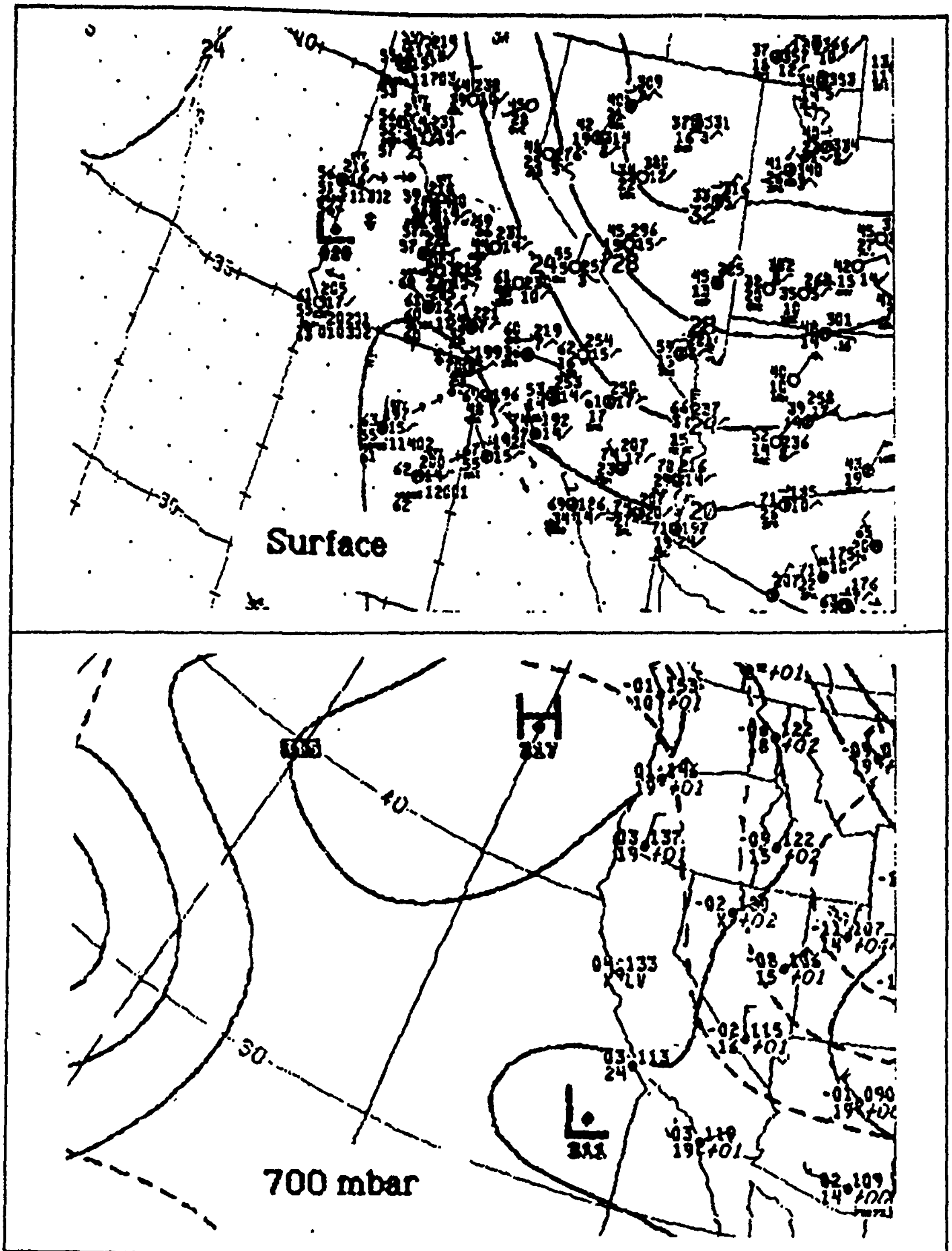


Figure 23. Surface and 700mbar Conditions for Case 1

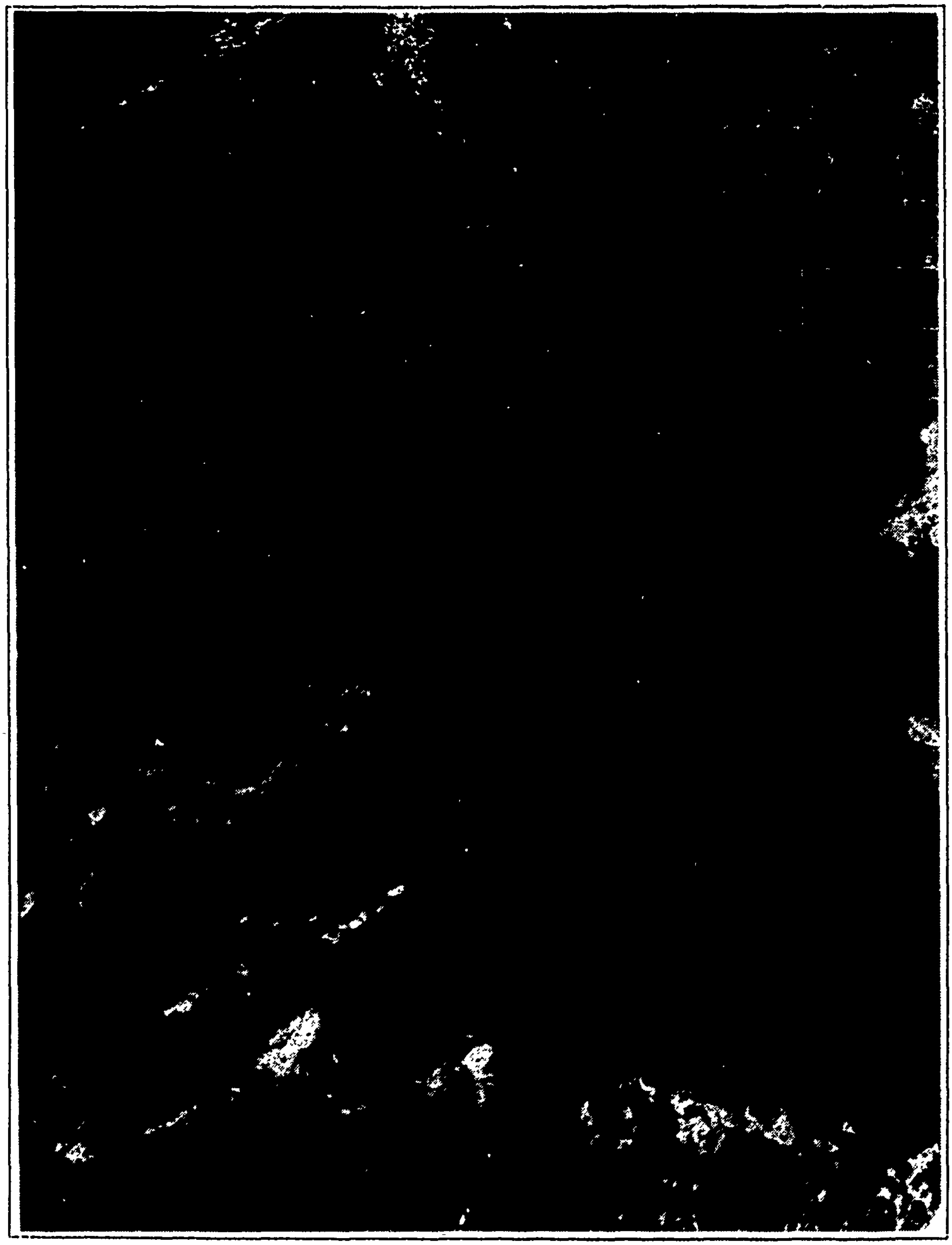
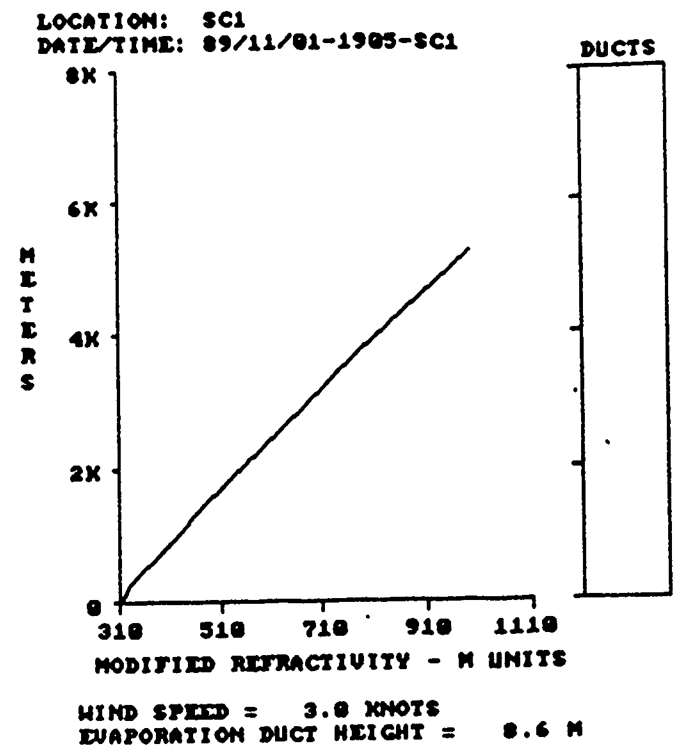


Figure 24. Satellite Imagery for Case I (1901Z, 891101)



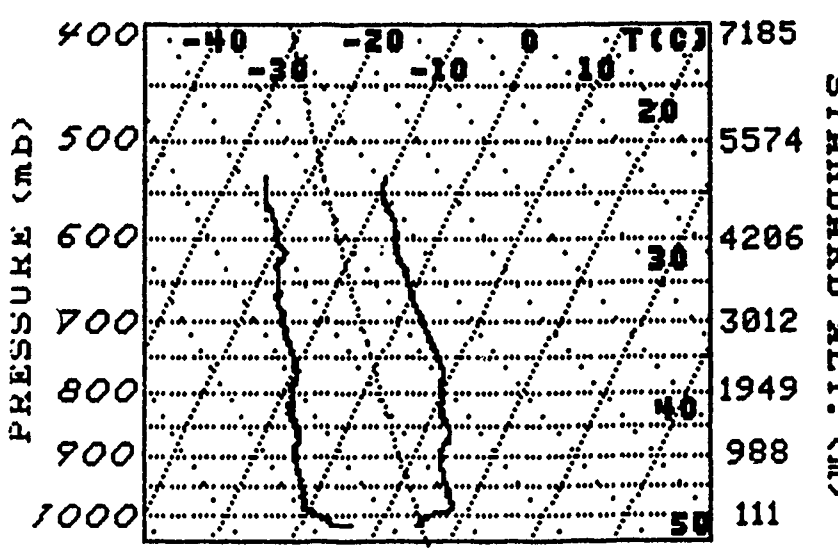


Figure 25. M Profile and Skew-T Plot for Case 1

2. Case two

- Location: 36-19.96 N, 123.01.86 W.
- Date/Time: 02 Nov 89, 1655 Z.

Figure 26 and Figure 27 show the surface and aloft synoptic patterns close to the time that the rawinsonde was launched. The satellite imagery was taken within six minutes of launch while the data from the surface and 700 mbar charts are approximately one and five hours old respectively. These features were interpreted for use in questions 5 - 15 of Appendix B. The local weather conditions were noted as mainly clear with less than five percent cloud cover and included a land to sea flow of warmer air. The IREPS refractive conditions summary for this rawinsonde launch indicated the presence of a surface based duct. The M profile in Figure 28 depicts rapidly decreasing M values from the surface up to approximately 200 m where M gradient begins to increase in a steady manner with height. The skew-T diagram of Figure 28 depicts the abnormal temperature and humidity profile near the surface which resulted in the surface based duct. Communication ranges would be extended in the duct with possible holes occurring above the top of the duct.

The IPDO calculation for case two indicated that ducting was *very likely.* Question number 19 of the IPEDBA suggests that the base of the duct is at the surface. The IPFRC then predicted correctly both the occurrence and type of duct present in this case. The IPFRC was not able to predict the height of the duct using the table in Appendix B because the area was not anticyclonic and was not an elevated duct.

3. Case three

- Location: 36-41.14 N, 121-32.33 W.
- Date/Time: 05 Nov 89, 1823 Z.

Figure 29 and Figure 30 show the surface and aloft synoptic patterns close to the time that the rawinsonde was launched. The satellite imagery was taken within eight minutes of the launch while the data from the surface and 700 mbar charts were approximately 23 minutes and 5.5 hours old respectively. The local weather conditions were noted as cloudy with a 50 percent cover of stratus type clouds. The wind direction was westerly at approximately 16 knots, and even though the PT. SUR was only three miles from shore, no land to sea breezes were noted. The IREPS refractive conditions summary for this rawinsonde launch indicated a single elevated duct extending from 450 m to 690 m. The M profile of Figure 31 illustrates the strength, height and thickness

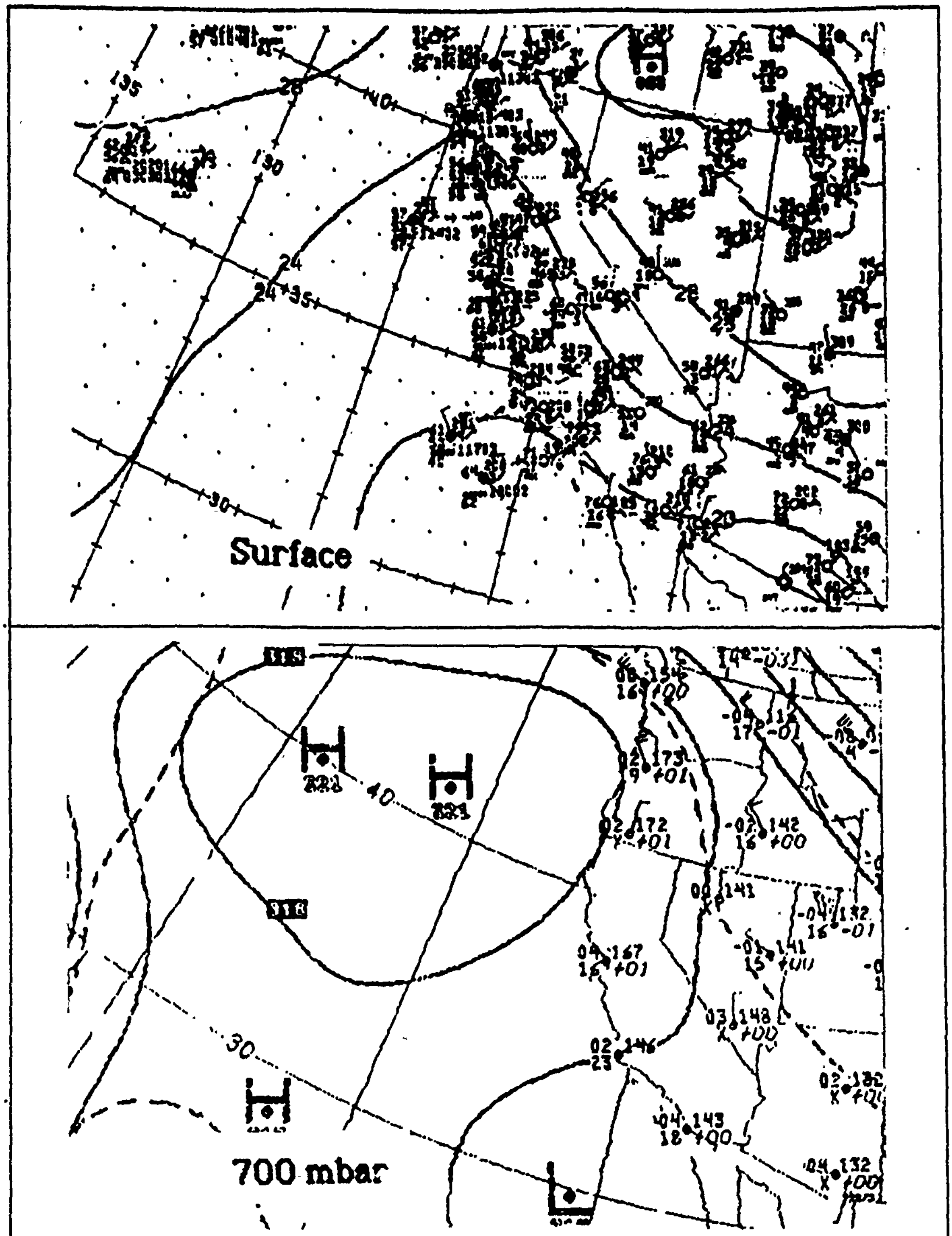


Figure 26. Surface and 700mbar Conditions for Case 2

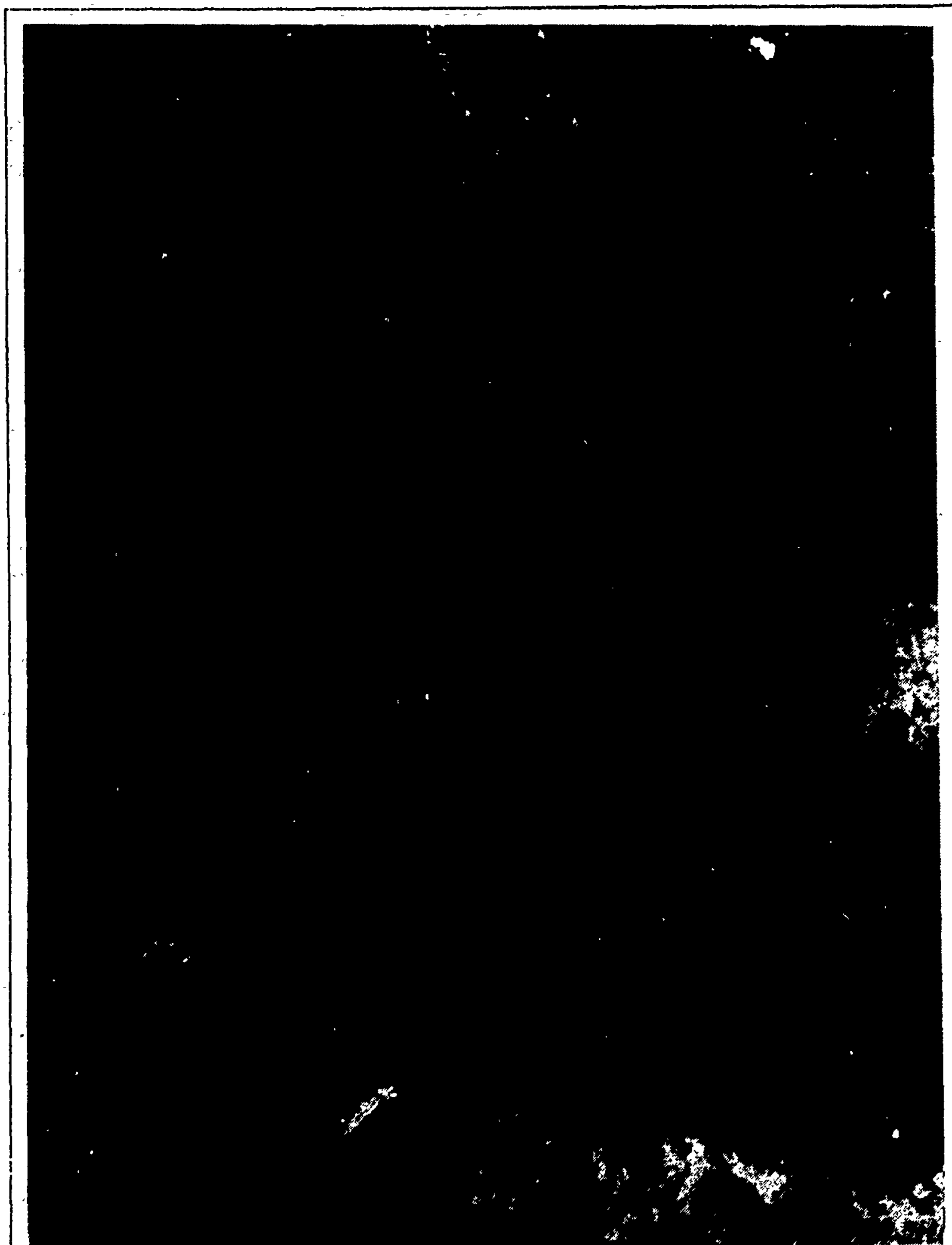


Figure 27. Satellite Imagery for Case 2 (1701Z, 891102)

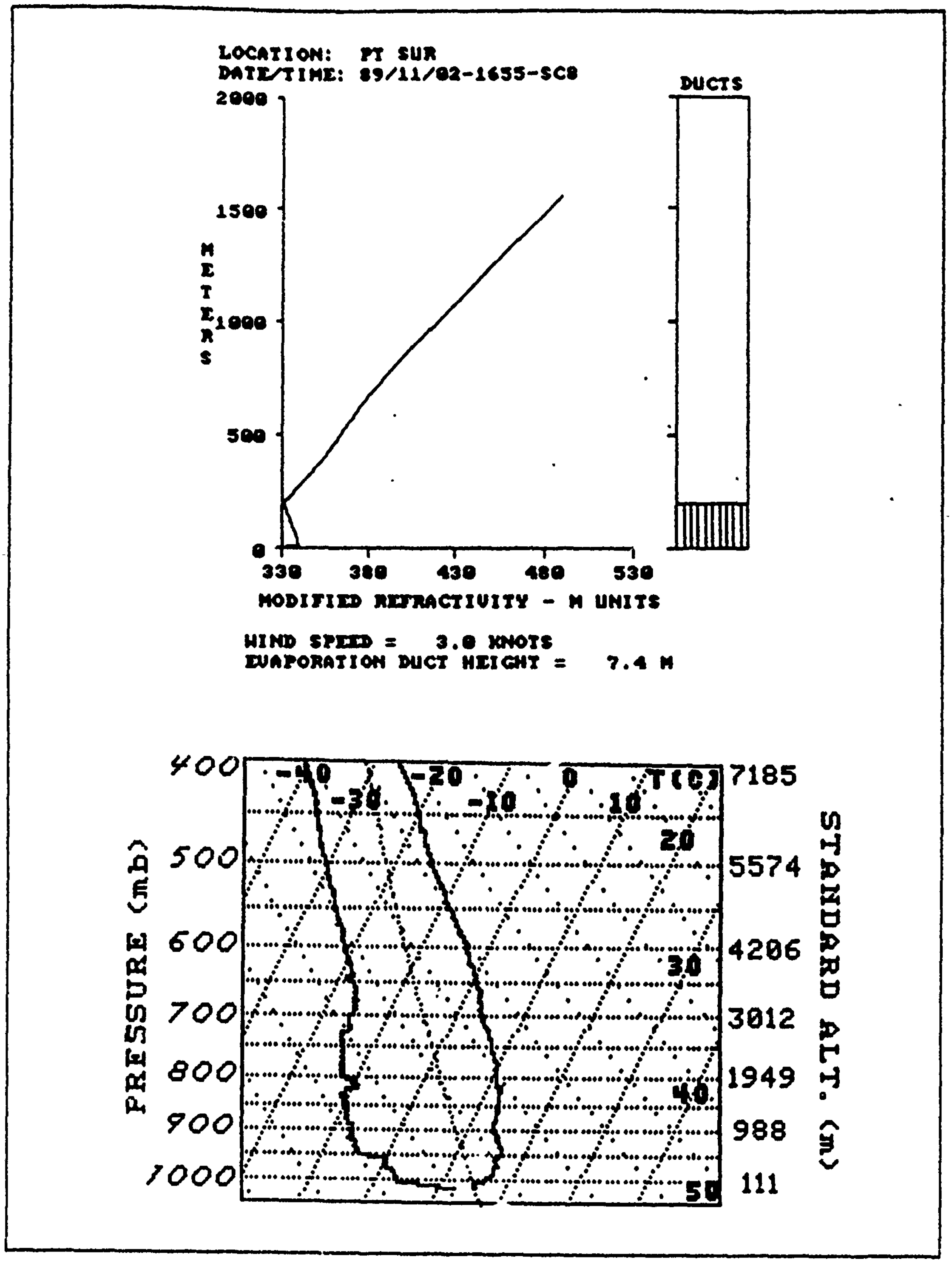


Figure 28. M Profile and Skew-T Plot for Case 2

of the elevated duct while the skew-T plot indicates the important role that humidity played in forming this elevated duct. The heavy lines near the top of the skew-T plot indicate areas where the rawinsonde signal was lost, and these lines can be ignored. Surface-to-surface communication ranges would be unaffected by this duct, but extended air-to-air communication could be expected if aircraft were located in the elevated duct.

The IPDO calculation for case three indicated that ducting was *probable*. Although the IPDO doesn't predict that ducting is *very likely*, the *probable* prediction is deemed sufficient to suggest the presence of ducting. The appearance of stratus on the satellite imagery is smooth and uniform. Thus question 21 (b) of Appendix B indicates that the base of the probable duct is 0 - 1000 feet. The actual base of the duct does fall within this range.

4. **Case four**

- Location: 36-37.26 N, 121-58.24 W.
- Date/Time: 05 Nov 89, 2040 Z.

This rawinsonde launch was conducted only a little more than two hours after the rawinsonde launch used for case three. The geographic location of the two launches was within 5 nautical miles of each other. Basically, the same synoptic meteorological conditions affected this launch, and they can be seen on the same figures used for case three. The local weather conditions included approximately 30 percent cloud cover, but the clouds tended to be closer to the surface than in case three. The wind was from 295 T and it had increased to approximately 23 knots. The IREPS refractive conditions summary for this rawinsonde launch indicated the presence of both a surface based and elevated duct. The modified refractivity graph in Figure 31illustrates rapidly decreasing M values from the surface to 46 m where the M gradient then sharply reversed itself and caused the surface based duct. The M values continued to increase until M reached 446 m. The M values were then reversed up to an altitude of 687 m and caused the elevated duct. The skew-T plot in Figure 31 illustrates the temperature and humidity differentials which resulted in both the elevated and surface based ducts. The surface based duct would cause extended ranges for surface-to- surface communications and extended ranges for surface-to-air and air-to-air if the antennas were located within the duct. The elevated duct would provide extended ranges for aircraft flying within the duct.

The IPDO calculation for case four was identical to the calculation for case three and indicated that ducting was *probable*. Question 21 (b) of Appendix C indicates that the duct base is in the range of 0 - 1000 feet. The surface based duct would fall into

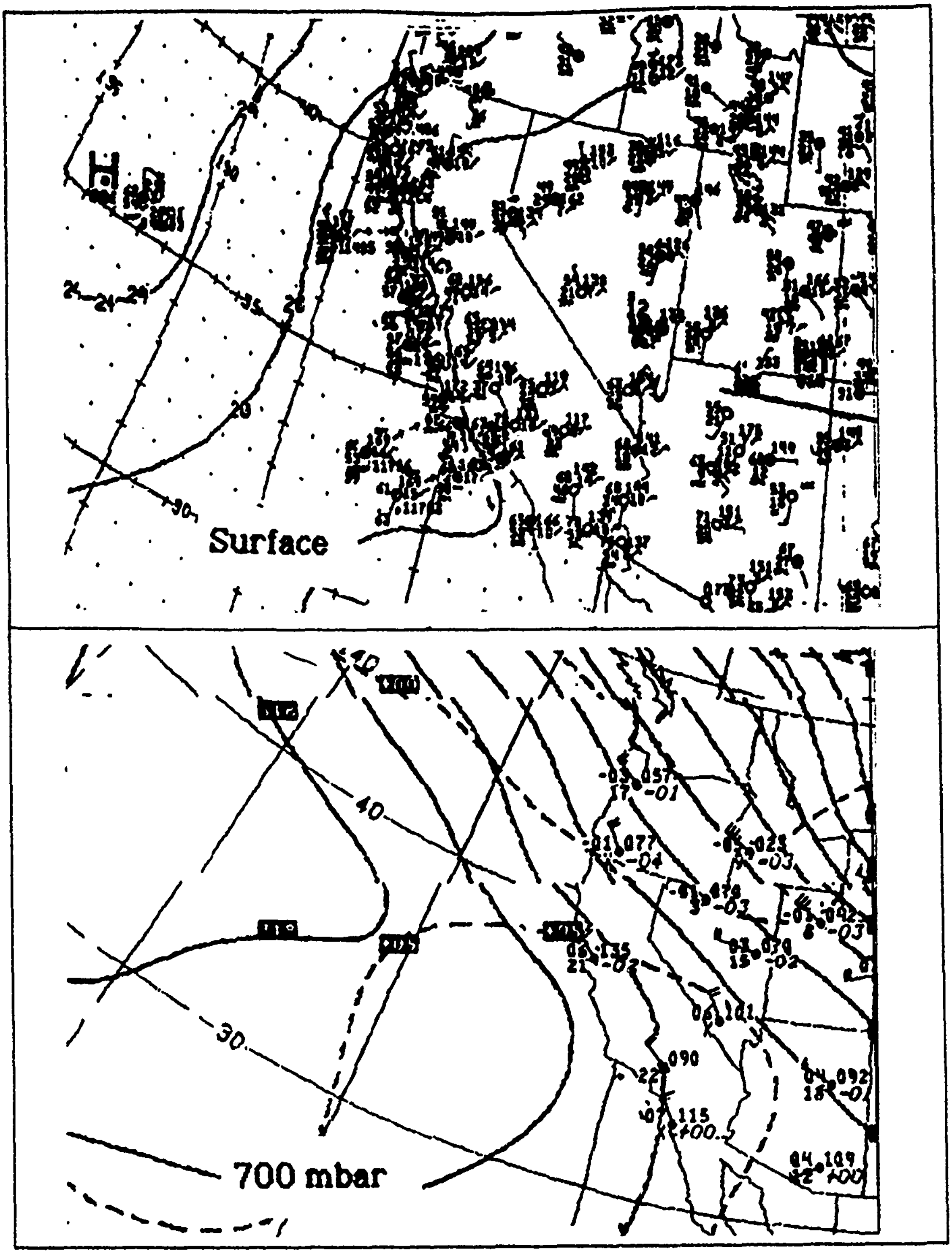


Figure 29. Surface and 700mbar Conditions for Cases 3 and 4

Figure 30. Satellite Imagery for Cases 3 and 4 (1831Z, 891105)

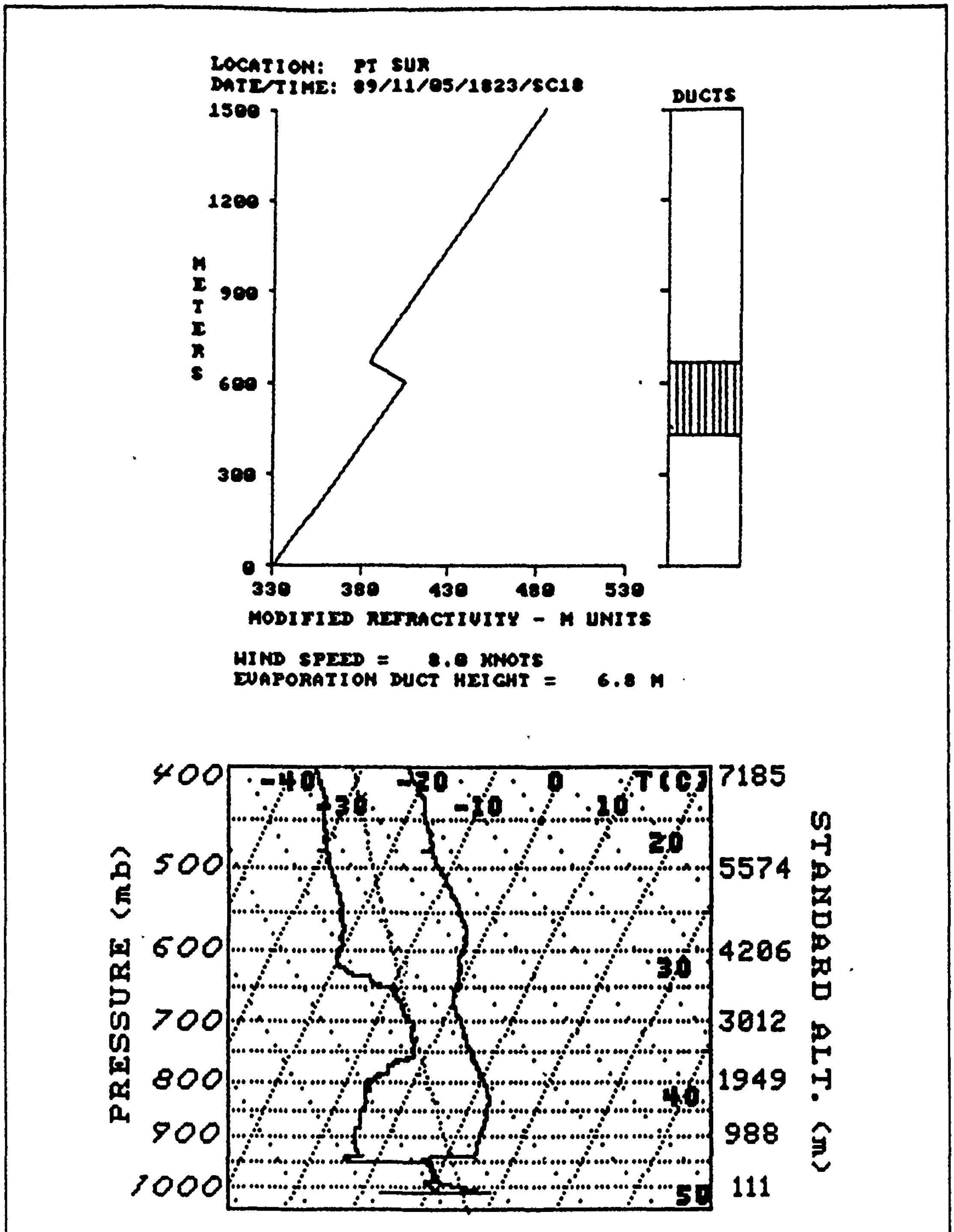


Figure 31. M Profile and Skew-T Plot for Case 3

this range, but the elevated duct with its base at 446 m (1463 feet) far exceeds the calculated maximum base altitude of 1,000 feet. Although the IPDO indicated that ducting was *probable* and successfully predicted the surface based duct, it failed to predict the presence of the associated elevated duct for this case.

5. Case five

- Location: 36-04.18 N, 122-15.62 W.
- Date/Time: 07 Nov 89, 0445 Z.

Figure 33 and Figure 34 show the surface and aloft synoptic patterns close to the time of launch. The satellite imagery was taken within 14 minutes of the launch while the data on the surface and 700 mbar charts were both 4.75 hours old. These features were interpreted for use in questions 5 - 15 of Appendix B. The local weather conditions were noted as mainly clear with a slight wind coming from the northwest. The IREPS refractive conditions summary for this rawinsonde launch indicated two distinct elevated ducts. The M profile of Figure 35 illustrates the two negative slope reversals of the M gradient and the two distinct elevated ducts which resulted. The skew-T plot of Figure 35 illustrates the effects that humidity and temperature had in forming the ducts. Communication ranges would be normal in all cases except air-to-air, which would experience extended ranges if the aircraft were located within the duct.

The IPDO calculation for case five indicated that ducting was *possible.* Questions 18 and 20 of Appendix C indicate that two ducts may be present; one with a base height of 3100 feet and the other with a base height of zero feet (a surface based duct). The actual base heights were approximately 760 feet and 1840 feet which do not correlate to either of the IPEDBA predictions. The actual ducting in this case, as indicated by IREPS, was quite weak and may have been produced by sporadic gusts of warm, moist air originating from the shore. If this was the case, the IPDO prediction that ducting was just *possible* would be a good prediction based solely upon the synoptic meteorological parameters.

D. CONCLUSION

The results from cases one through five indicate that in certain cases, refractive conditions can be successfully predicted by using the IPFRC. Five cases can certainly not prove or disprove the usefulness of the IPFRC, but the positive results should provide an incentive for future extensive testing and refining of the procedure. This procedure could be useful, if proven accurate, by fleet ships that have facsimile machines but currently have no other means of assessing refractive conditions.

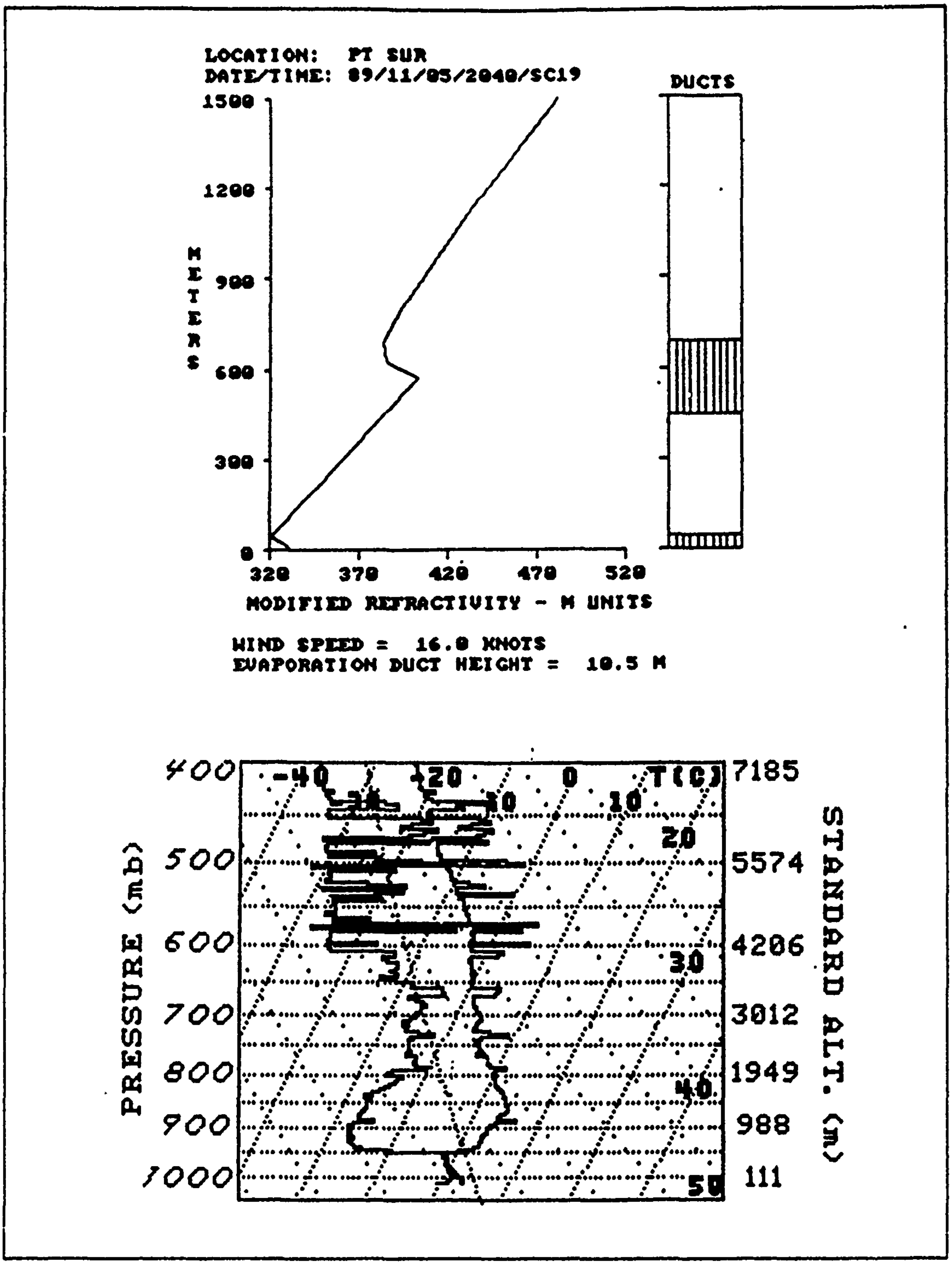


Figure 32. M Profile and Skew-T for Case 4

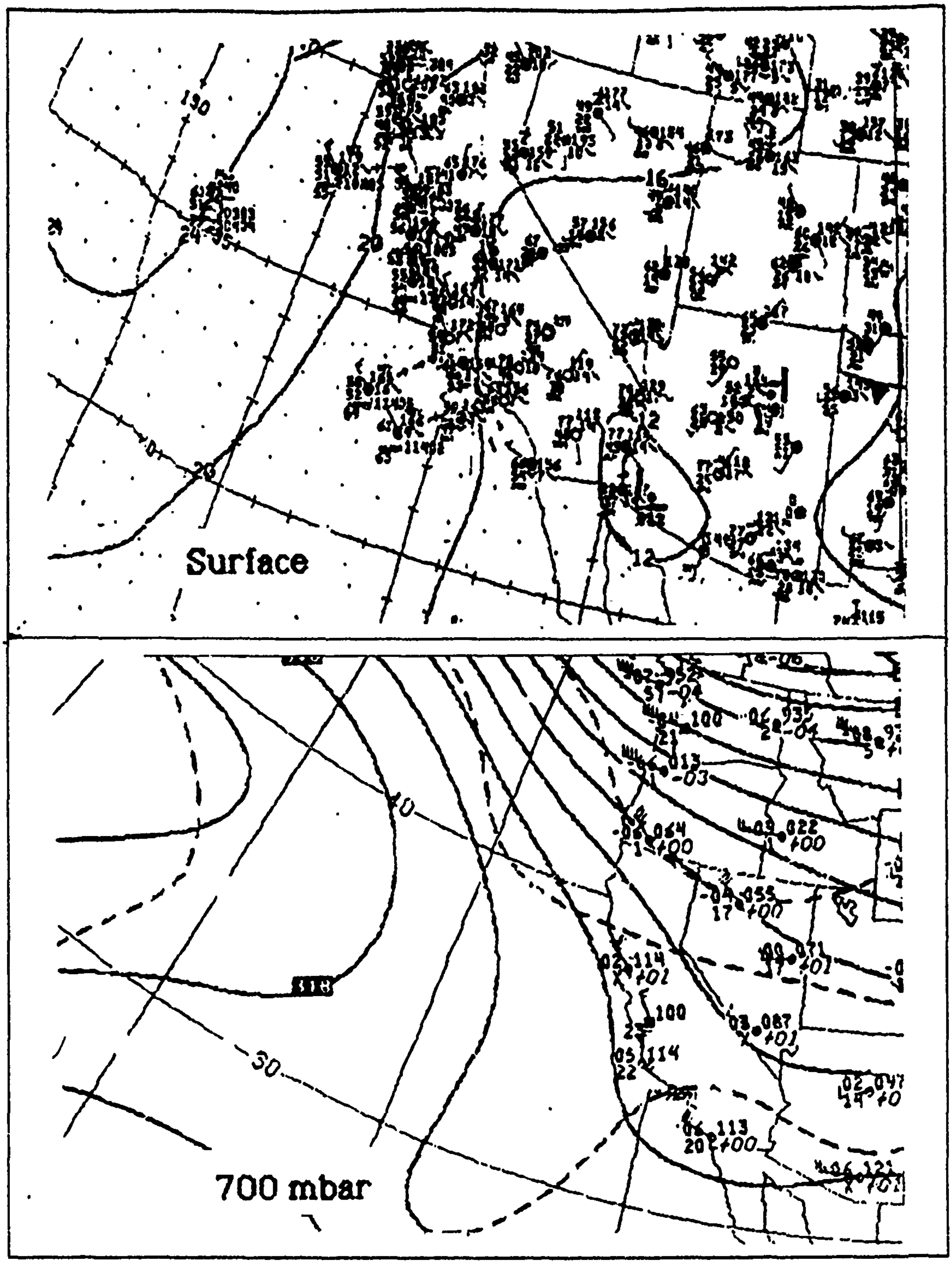
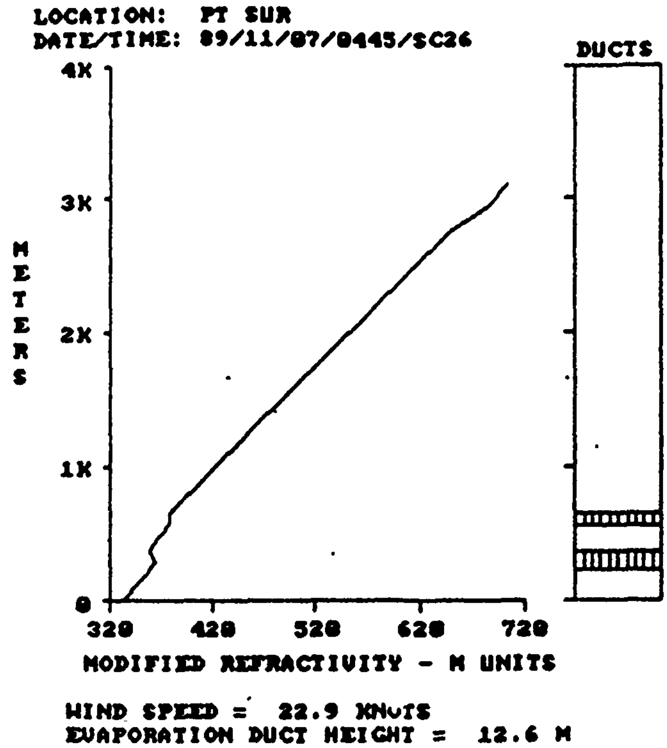


Figure 33. Surface and 700mbar Conditions for Case 5

Figure 34. Satellite Imagery for Case 5 (0431Z, 891107)



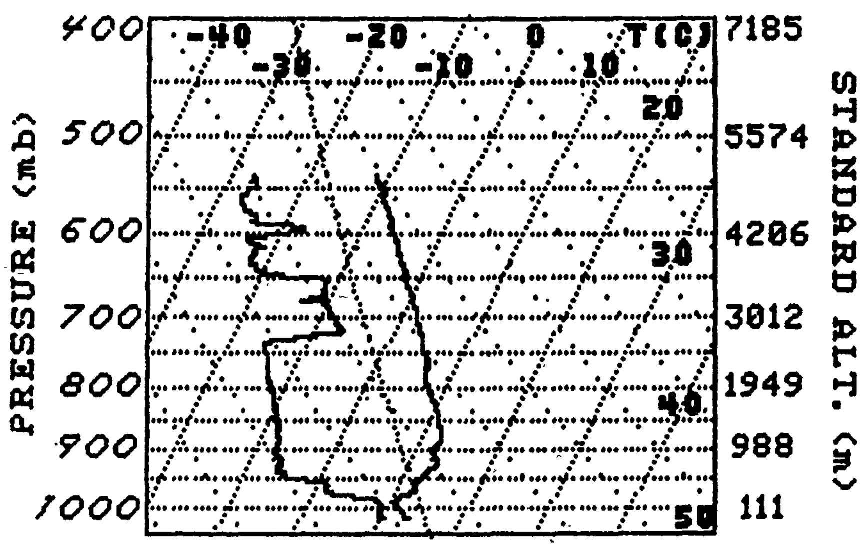


Figure 35. M Profile and Skew-T Plot for Case 5

V. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

It is clearly evident that nonstandard gradients of temperature, pressure and humidity dramatically affect communication ranges. At times, refractive conditions enhance communication ranges and enable ships and aircraft to communicate far beyond the horizon in the VHF and UHF spectrums. These same refractive conditions may conversely degrade communication ranges if an aircraft flying above the duct is trying to communicate with a ship below the duct. Tactical decision makers need to know how these refractive conditions will affect communications between their assets and thus IREPS was developed.

IREPS has been thoroughly tested and has proven to be an accurate refraction assessment product when the input data is derived from a rawinsonde at the point and time of interest. The fact remains that most ships in the fleet today do not have IREPS or rawinsondes and are unable to independently assess the refractive conditions for their point of interest. Without any indication as to the refractive conditions present, it is nearly impossible to predict communication ranges or to determine effective EMCON conditions.

PACMISTESTCEN's IPFRC shows much promise in determining refractive conditions from synoptic weather parameters using nothing more than weather charts and satellite imagery. The results of the IREPS-IPFRC comparison from the research cruise showed a 60 % success rate for the IPFRC. Although the data set for this comparison was very small and the results cannot be considered conclusive, the experiment did test the types of refraction most commonly encountered over areas of open ocean. An advantage of the IPFRC is that it would cost very little to implement if it was ever refined to the point where its accuracy would meet naval standards. It would also give ships not equipped with IREPS or TESS a tool to assess refractive conditions anytime, anywhere. Currently, the major drawback of such a procedure is its accuracy. The IPFRC also does not provide assessment products such as the IREPS generated propagation conditions summary or coverage displays.

B. RECOMMENDATIONS

It is currently unrealistic to recommend the installation of IREPS or TESS on all naval vessels due to the considerable cost of the system and associated training of per-

sonnel to run it. Instead, a continued evaluation, refinement and testing of the IPFRC could be performed and possibly culminate in an acceptable refractive assessment tool for use by naval vessels.

APPENDIX A. PACMISTESTCEN'S THUMB RULES

[Ref 15 : pp. 26-30]

Factors Favorable to Elevated Duct Occurrence at Present/Predicted Location

1. Location within SE and SW quadrants of subtropical highs (for Bermuda area, SW and NW quadrants)
2. Anticyclonic curvature of surface isobars
3. Decreasing distance to center of high
4. Increasing surface pressure (especially PS > 1015 mbar)
5. $T_{sfc} - T_{700} < 15^{o}C$, or $T_{700} = 5$ to $10^{o}C$
6. Location outside active frontal zone
7. Presence of well-defined haze layers
8. Presence of stratus clouds (not accompanied by rain. Drizzle from stratus is acceptable)
9. Extensive stratus or stratocumulus sheet observed on visual or infrared satellite imagery with granular or cellular appearance
10. Evidence of a temperature inversion
11. Weak winds aloft
12. Lack of extensive and thick mid-level cloudiness

Factors Favorable to Surface Based (Non-Evaporative) Duct Occurrence at Present/Predicted Location

1. Warm (temperatures higher than sea surface temperature), dry offshore flow
2. Stratus or fog deck with top at 1,000 feet or below
3. Large hole within stratus covered area as observed on satellite imagery, or similar stratus-surrounded clear region extending seaward from continent
4. Stars or moon dimly visible through dense surface fog
5. Very smooth, white and uniform stratus observed on visual satellite imagery (as compared with more typical granular or cellular patterns)

Factors Affecting Height of Elevated Ducts at Present/Predicted Location
(also see table 4 for assessments of surface based ducts)

1. Maximum occurrence of ducts between 4,000 and 6,000 over subtropical ocean areas
2. Mean duct height for anticyclones can be estimated from sea surface temperatures in accordance with table 2. Mean height applies generally to within 5° latitude of high center
3. General increase in mean duct height of about 200 meters (about 650 feet) per 5°C increase in sea surface temperature
4. Lowest duct heights in SE quadrant of high (about 1,500 feet lower than in center of high)
5. Highest duct heights in SW or NW quadrant of high (about 1,500 feet higher than in center of high). (Some tendency for secondary, lower duct in SW and NW quadrants.)
Lowering heights may be observed in advance of active cold fronts until arrival of the frontal region itself

Factors Favorable to Standard Refractive Conditions at Present/Predicted Location

1. Location within NW quadrants of subtropical highs or northern half of migratory highs (except for Bermuda area)
2. Under or immediately following active front
3. Cyclonic curvature of surface isobars
4. Closeness to low pressure area
5. Surface pressures less than 1,000 mbar
6. Cold air aloft ($T_{700} < -10°C$)
7. Presence of cumulus and deep convective clouds (with or without showery precipitation)
8. Absence of temperature inversions
9. Unstable, windy conditions
10. Open celled clouds behind frontal system as observed on satellite imagery

NOTE: Studies and observations have shown that conditions characterized by multi-level layered clouds result in subrefractive conditions or subnormal ranges. Such conditions may be found interspersed with layers exhibiting standard as well as ducting conditions.

APPENDIX B. PACMISTESTCEN'S IPFRC

[Ref 15 : pp. 30-33]

INTERIM PROCEDURE FOR DETERMINING DUCT OCCURRENCES

1. Can present refractivity be determined by direct measurement (sounding or refractometer) at position of interest? If yes, note duct occurrence, strength, and height.

2. If not, or if future refractivity is desired, obtain FNOC surface analysis or prognosis nearest to time of interest and note location at time of interest.

3. Obtain FNOC 700 mbar analysis or prognosis nearest to time of interest and note location at time of interest.

4. Tabulate points in steps 5 through 14.

5. Determine surface pressure (Ps) at location of interest.

If PS<1000 mbar, NOTE	0 Points
If PS 1000-1009 mbar, NOTE	1 Point
If PS 1010-1019 mbar, NOTE	2 Points
If PS> 1020 mbar, NOTE	3 Points

6. Determine curvature (CURV) of nearest surface isobar to point of interest.

If CURV is cyclonic, NOTE	0 Points
If CURV is neutral, NOTE	1 Point
If CURV is anticyclonic, NOTE	2 Points

7. Determine distance (DH) of point of interest to center of surface high of governing airmass.

If DH is > 20º latitude, NOTE	0 Points
If DH is 11º-20º latitude, NOTE	1 Point
If DH is 6º-10º latitude, NOTE	2 Points
If DH is 0º-5º latitude, NOTE	3 Points

8. Determine distance (DF) of point of interest to nearest analyzed surface front.

If DF is 0º-5º latitude, NOTE	0 Points
If DF is 6º-10º latitude, NOTE	1 Point
If DF is 11º-20º latitude, NOTE	2 Points
If DF is > 20º latitude, NOTE	3 Points

9. Determine surface wind direction (WD) at point of interest. Assume wind deviation of 15º from geostrophic. (Outward from highs and inwards towards lows.)

(a) For Western Atlantic:

If WD is 061º - 120º, NOTE	2 Points
If WD is 121º - 180º, NOTE	3 Points
If WD is 181º - 240º, NOTE	0 Points
If WD is 241º - 300º, NOTE	1 Point
If WD is 301º - 360º, NOTE	1 Point
If WD is 001º - 060º, NOTE	1 Point

(b) For all other North Atlantic and North Pacific stations:

If WD is 061º - 120º, NOTE	2 Points
If WD is 121º - 180º, NOTE	1 Point
If WD is 181º - 240º, NOTE	0 Points
If WD is 241º - 300º, NOTE	1 Point
If WD is 301º - 360º, NOTE	2 Points
If WD is 001º - 060º, NOTE	3 Points

10. Infer stability (DT) at time and point of interest by using either (a) or (b) below.

(a) Compare 700 mbar temp (ºC) with surface temp (ºC) at point of interest. (If temps unavailable on prognosis, estimate temps from values observed on current analysis in same airmass at appropriate heights and locations.)

If Tsfc - T700 > 20º C, NOTE	0 Points

If Tsfc - T700 15 - 20 ºC, NOTE 1 Point
If Tsfc - T700 < 15º C, NOTE 2 Points

(b) Is there any available prediction or assessment of inversion layer at lowest 10,000 ft. (Use IREPS library if no information is available and 700 mbar forecast is unavailable. If inversion is forecast, NOTE 2 Points).

11. If T700 (T7)< -10º C, Subtract 3 Points

12. Is there an observation, or a strong basis for inferring offshore (land to sea) flow of warm, dry air at the surface at the point of interest (PI)?

If yes, NOTE 6 Points

13. Is point of interest in region of recognized daytime seabreezes? (Limited to within 50 miles of coastlines (SB))

If yes and in daytime, NOTE 1 Point

14. Infer existence of inversion layer at time and point of interest using either (a) or (b) below.

(a) If present observations show a distinct low level haze layer or non-rain producing stratus clouds at point of interest, and no airmass change is forecast, NOTE 4 Points (PH).

(b) If present satellite imagery shows widespread uniform stratus clouds at predicted point of interest and no airmass change is forecast, NOTE 4 Points (PST)

15. Compute weighted total including all parameters observed:

$$P\ Total = 10 \times \frac{Pps + Pc + Pdh + Pdf + Pwd + Pdt + Pt7 + PI + Psb + Ph + Pst}{Mps + Mc + Mdh + Mdf + Mwd + Mdt + Mt7 + MI + Msb + Mh + Mst}$$

where M is the relative weight of each parameter present. (When a parameter is not available, delete the corresponding values in both numerator and denominator):

Mps = 3	Mdf = 3	Mt7 = 3	Mh = 4
Mc = 2	Mwd = 3	Ml = 7	Mst = 4
Mdh = 3	Mdt = 2	Msb = 1	

For the region from the surface up to 10,000 feet:

If total < 0 to 2, predict ducts unlikely
If total > 2 to 4, predict ducts possible
If total > 4 to 6, predict ducts probable
If total > 6, predict ducts very likely

INTERIM PROCEDURE FOR DETERMINING DUCT BASE ALTITUDE

16. Determine sea surface temperature at location of interest using either current/recent actual measurement or climatology for appropriate month.

17. Obtain estimate of mean duct height (Zd) of anticyclone for region of interest using table 2.

18. Note surface wind direction (WD) as in step 9.

If WD is 301º - 060º, estimate height of duct base Zb = Zd - 1500 ft.
If WD is 061º - 090º, or if within 5º latitude of closest isobar of high, estimate Zb = Zd.
If WD is 091º - 180º, estimate height of duct base Zb = Zd + 1500 ft.

19. If region of interest is within low level offshore flow and within five degrees latitude of the coast, estimate height of duct base Zb = 0 (Surface based duct).

20. If no offshore flow occurs but region of interest (current assessments only) lies within clear hole on satellite imagery surrounded by low stratus

clouds, or clear slot extending from coast surrounded on all sides by low (smooth) stratus, estimate height of duct base Zb = 0. (Surface based duct).

2 Ia. If actual stratus base heights are available for current assessments, estimate Zb = 500 to 1000 feet lower than stratus base, or

2 Ib. If only satellite imagery is available (no charts or measured cloud heights), and if region of interest lies within stratus area, estimate Zb as follows:

If stratus is very smooth and uniform Zb = 0 to 1000 ft.

If stratus has granular appearance Zb = 500 to 3000 ft.

If stratus/stratuscumulus are very cellular (closed) or in dense bands Zb = 3000 to 5000 ft.

Approximate Mean Elevated Duct Heights (Z_D) for Specified Sea Surface Temperature Intervals (Intervals Smoothed and Interpolated).

Sea Surface Temperature (SST)		Height MSL (Z_D)	
(C)	(F)	(m)	(ft)
5-7	41-45	1000	3300
8-10	46-50	1200	3900
11-12	51-55	1300	4300
13-15	56-60	1400	4600
16-18	61-65	1500	4900
19-21	66-70	1600	5200
22-24	71-75	1700	5600
25-27	76-80	1800	6200
>27	>80	2000	6600

APPENDIX C. IPFRC CALCULATIONS

Case 1.

IREPS determination: no ducts present.

Rawinsonde launch . 01 Nov 89 1905 Z.

Launch Position: 36 - 47.71 N, 121 - 58.10 W.

Distance from shore: 4.8 miles.

1. No (for purpose of comparison only).
2. Obtained 01 Nov 89 1800Z Surface Analysis.
3. Obtained 01 Nov 89 1200Z 700 MB Analysis.
4. See 5 - 15.
5. Surface Pressure noted 1021.1 MB — 3 Pts Ps
6. CURV noted as cyclonic — 0 Pts Pc
7. Distance to center of surface High note as 9.8º. — 2 Pts DH
8. Distance to nearest front noted as > 20º. (passed) — 3 Pts DF
9. Surface wind direction noted as 068º. — 2 Pts WD
10. Infer stability (used condition (a)).

    $T_{surf} = 15.2^{\circ}C - T_{700} (+5^{\circ}C) = 10.2\ ^{\circ}C.$ — 2 Pts DT
11. T_{700} is not < -10º C. — 0 Pts T7
12. Land to sea flow of warm air noted. — 6 Pts PI
13. Daytime seabreezes recognized. — 1 Pt SB
14. Inversion layer noted using (a) or (b). — N/A PH

    0 Pts PST
15. $$P_{total} = 10 \times \frac{(3+0+2+3+2+2+0+6+1+N/A+0)}{(3+2+3+3+3+2+3+6+1+N/A+4)}$$

    $$= 6.33$$

Interim procedure indicates that ducting is very likely.

16. Sea surface temperature noted as 13.2º C.
17. Not Applicable since region of interest is cyclonic.

18. Wind Direction noted as 068º. Indicates that $Z_b - Z_t$.
19. Region is within 5º latitude of coast with low level offshore flow. This indicates $Z_b = 0$. (A surface base duct.)
20. N/A.
21a. N/A.
21b. No stratus clouds present.

Case II.

IREPS Determination: Surface based duct.
Ravinsonde launch: 02 Nov 89 1655Z.
Launch position: 36 - 19.96 N, 123 - 01.86 W.
Distance from shore: 55 miles.

1. No (for purpose of comparison only).	
2. Obtained 02 Nov 89 1800Z Surface Analysis.	
3. Obtained 02 Nov 89 1200Z 700 MB Analysis.	
4. See 5 - 15.	
5. Surface pressure noted as 1021.95 MB.	3 Pts Ps
6. CURV noted as cyclonic.	0 Pts Pc
7. Distance to center of surface High noted as 7º.	2 Pts DH
8. Distance to nearest front noted as 15º. (passed)	2 Pts DF
9. Surface wind direction noted as 054º.	3 Pts. WD
10. Infer stability (used condition (a)).	
$T_{surf} = 16.57ºC - T_{700} (+2ºC) = 14.57ºC$.	2 Pts DT
11. T_{700} is not $< -10º$ C.	0 Pts T7
12. Land to sea flow of warm air noted.	6 Pts PL
13. Daytime seabreezes not recognized.	0 Pts PSB
14. Inversion layer noted using (a) or (b).	N/A PH
	4 Pts PST

15.

$$P_{total} = 10 \times \frac{(3+0+2+2+3+2+0+6+0+N/A+4)}{(3+2+3+3+3+2+3+6+1+N/A+4)}$$

- 7.33

Interim procedure indicates that ducting is very likely.

16. Sea surface temperature noted as 16.57º C.
17. Z_d Mean duct height estimate is N/A since region is cyclonic.
18. Wind direction noted as 069º. Indicates that $Z_b = Z_d$.
19. yes, $Z_b = 0$. (Surface based duct.)
20. N/A.
21a. N/A.
21b. N/A No stratus clouds.

Case III.

IREPS determination: Elevated duct.
Rawinsonde launch: 05 Nov 89 1823 Z.
Launch Position: 36 - 41.14 N, 121 - 32.33 W.
Distance from shore: 29 miles.

1.	No (for purpose of comparison only).	
2.	Obtained 05 Nov 89 1800Z Surface Analysis.	
3.	Obtained 05 Nov 89 0000Z 700MB Analysis.	
4.	See 5 - 15.	
5.	Surface pressure noted 1017.2 MB.	2 Pts Ps
6.	CURV noted as anticyclonic.	2 Pts Pc
7.	Distance to center of surface High noted as 9º.	2 Pts DH
8.	Distance to nearest front noted as 9º (passed).	1 Pt DF
9.	Surface wind direction noted as 270º.	1 Pt WD
10.	Infer stability (used condition (a)).	
	$T_{surf} = 12.41^{\circ}C - T_{700} (+5^{\circ}C) = 7.41^{\circ}C$.	2 Pts DT
11.	T_{700} is not $< -10^{\circ}C$.	0 Pts T_7
12.	Land to sea flow of warm air not recognized.	0 Pts PL
13.	Daytime seabreezes recognized.	1 Pt SB
14.	Inversion layer noted using (a) or (b)	N/A PH
		4 Pts PST

15. $P_{total} = 10 \times \frac{(2+2+2+1+1+2+0+0+1+N/A+4)}{(3+2+3+3+3+2+3+6+1+N/A+4)}$

$= 5.00$

Interim procedure indicates that ducting is probable.

16. Sea surface temperature noted as 13.2º C.
17. Z_d Mean duct height estimate = 4600 feet.
18. Wind direction noted as 270 º. No Z_b indication.
19. N/A.
20. N/A.
21a. N/A.
21b. Stratus appear smooth and uniform. Z_b = 0 - 1000 feet.

Case IV.

IREPS determination: Surface based and elevated ducts.
Rawinsonde launch: 05 Nov 89 2040Z.
Launch position: 36 - 37.26 N, 121 - 58.24 W.
Distance from shore: 3.8 miles.

1.	No (for purpose of comparison only).	
2.	Obtained 05 Nov 89 1800Z Surface Analysis.	
3.	Obtained 05 Nov 89 0000Z 700 MB Analysis.	
4.	See 5 -15.	
5.	Surface pressure noted 1019.0 MB.	2 Pts. Ps
6.	CURV noted as anticyclonic.	2 Pts. Pc
7.	Distance to center of surface High noted as 9º.	2 Pts DH
8.	Distance to nearest front noted as 9º (passed).	1 Pt DF
9.	Surface wind direction noted as 294º.	1 Pt WD
10.	Infer stability (used condition (a)).	
	T_{surf} = 12.9º C - T_{700} (+5º C) = 7.9º C.	2 Pts. DT
11.	T_{700} is not < - 10º C.	0 Pts. T7
12.	Land to sea flow of warm air not noted	0 Pts PI

13. Daytime seabreezes recognized . 1 Pt SB
14. Inversion layer noted using (a) or (b) N/A PH
4 Pts PST.

15. $P_{total} = 10 \times \frac{(2+2+2+1+1+2+0+0+1+N/A+4)}{(3+2+3+3+3+2+3+6+1+N/A+4)}$
$= 5.00$

Interim procedure indicates that ducting is probable.

16. Sea surface temperature noted as 13.8 ºC.
17. Z_d Mean duct height estimate = 4600 feet.
18. Wind direction noted as 294º.
19. N/A.
20. N/A.
21a. N/A.
21b. Stratus appears smooth and uniform. Z_b = 0 - 1000 feet.

Case V.

IREPS determination: Two elevated ducts.
Rawinsonde launch: 07 Nov 89 0445 Z.
Launch Position: 36 - 04.18 N, 122 - 15.62 W.
Distance from shore: 28.5 miles.

1. No (for purpose of comparison only).
2. Obtained 07 Nov 89 0600Z Surface Analysis.
3. Obtained 07 Nov 89 0000Z 700 MB Analysis.
4. See 5 - 15.
5. Surface pressure noted as 1020.0 3 Pts. Ps
6. CURV noted as anticyclonic. 2 Pts. Pc
7. Distance to center of surface High noted as 11º. 1 Pt DH
8. Distance to nearest front noted as 4.6º (passed). 0 Pts DF
9. Surface wind direction noted as 341º. 2 Pts WD
10. Infer stability (used condition (a)).
T_{surf} = 13.9º C - T_{700} (+1º C) = 12.9º C. 2 Pts. DT

11. T_{700} is not < - 10° C. | 0 Pts. T_7
12. Land to sea flow of warm air not noted. | 0 Pts P_l
13. Daytime seabreezes recognized. | 1 Pt SB
14. Inversion layer noted using (a) or (b). | N/A PH

0 Pts PST

15. $P_{total} = 10 \times \frac{(3+2+1+0+2+2+0+0+1+N/A+0)}{(3+2+3+3+3+2+3+6+1+N/A+4)}$

$= 3.67$

Interim procedure indicates that ducting is possible.

16. Sea surface temperature noted as 13.9° C.
17. Z_d Mean duct height estimate = 4600 feet.
18. Wind direction noted as 341°. Indicates that $Z_b = Z_d - 1500$ feet.
    Z_b = 4600-1500 = 3100 feet.
19. N/A
20. Region of interest does lie within a hole on satellite imagery surrounded by stratus. Indicates $Z_b = 0$ (Surface based duct.)

21a. N/A

21b. N/A.

LIST OF REFERENCES

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